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THE UNIVERSITY OF ALBERTA

# An Analysis Of The Demand For New Wood Panels And Other Forest Products In The Canadian And United States Construction Industries

by

© BRETT MILES GELLNER

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIRMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

IN

FOREST ECONOMICS

DEPARTMENT OF RURAL ECONOMY

EDMONTON, ALBERTA

SPRING 1989

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled AN ANALYSIS OF THE DEMAND FOR NEW WOOD PANELS AND OTHER FOREST PRODUCTS IN THE CANADIAN AND UNITED STATES CONSTRUCTION INDUSTRIES submitted by BRETT M. GELLNER in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE in FOREST ECONOMICS.

.....

Supervisor

.....

.....

.....

Date February 16, 1987

## DEDICATION

This thesis is dedicated to my wife Jeanette. Her support and patience helped make it all possible.

## ABSTRACT

This study focuses on modeling the derived demand for the relatively new nonveneered structural wood panels (NSP) by the Canadian and U.S. construction industries. The demand for NSP has been increasing rapidly since the late 1970s in both Canada and the United States. It is hypothesized that the demand for NSP is not only governed by relative prices and technological change but also by the increasing market acceptance of these products, giving rise to dynamic factor demand adjustments.

Three general models are used to test this hypothesis: the static, dynamic partial adjustment and dynamic logistic model. A Generalized Leontief cost function is adopted as the underlying foundation of these models.

Results obtained from quarterly data over the period 1979-3 - 1986-4 reveal that, out of all the models estimated, the dynamic partial adjustment with Hicks biased technical change provides the best statistical representation of both the Canadian and U.S. construction industries. Selection of this model indicates that construction firms have not instantaneously adjusted their factors of production to long-run equilibrium levels during the historical period, an assumption that is maintained in static models and in most of the available literature on these industries. However, the Canadian industry has immediately adjusted NSP to long-run levels which suggests that market acceptance has not been a factor influencing the demand for NSP in Canada. In the U.S., however, the existence of dynamic responses of demand for NSP to changes in factor prices suggests that this product is still an

innovative product in that country.

## ACKNOWLEDGEMENTS

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# Chapter 1

# INTRODUCTION

This study examines the demand for a relatively new forest product - non-veneered structural wood panels (NSP) - by the Canadian and United States construction industries and the economic relationships between NSP and other inputs used in these industries. This is accomplished by developing and testing several comprehensive econometric models that tie together the theories of diffusion with the neoclassical theory of the firm.

Since NSP is a relatively new product, there is not yet a comprehensive understanding of the economic behavior of consuming firms towards these products and their potential for substituting for competing commodities. Equally important, there are very few quantitative results regarding market penetration of non-veneered structural wood panels for forecasting and policy analysis purposes. These reasons coupled with the lack of appropriate models for measuring the market penetration of innovative forest products warrants the need for this research.

## 1.1 GENERAL PROBLEM AND PREVIOUS RESEARCH

The theory of derived demand has become widely used in modeling the demand for forest products since the majority of these goods are consumed by another production process. The forest sector is a producer of raw materials and processed products, as well as other non-market goods. Most raw materials are consumed by the forest sector itself

whereas processed goods are used as factor inputs into industries such as construction, furniture, printing and publishing.

Several econometric studies of the forest product markets have employed the concept of factor demand to specify and estimate demand functions for wood products.[1] In these studies, it has been assumed that the demand for an input and substitution among inputs is determined from changes in (1) relative factor prices, (2) the scale of production, and (3) the aggregate state of technology, and that adjustments of input quantities to any of these changes are instantaneous and costless. These assumptions may be adequate for well established forest products, such as lumber and plywood, but it is not entirely clear that they are sufficient for explaining the demand for newly established, innovative products.

The literature on technical change suggests that the derived demand for an innovation and its ability to compete with existing products may not only be governed by factor prices, scale effects and technological change but also by its level of acceptance by the consuming industry. Since there is typically some level of risk and uncertainty associated with the innovation, it is argued that firms will not instantaneously adjust their use of these inputs to their long-run expansion path when confronted with an economic shock. In the short-run, therefore, a firm will maximize its profits (or minimize costs) subject to not only the constraints imposed by the given input

---

[1]The more recent studies include Adams & Haynes (1980), McKillop et al (1980), Rockel & Buongiorno (1982), Doran & Williams (1982), and Sharma (1986).

prices, technology and production structure but also to an adjustment cost constraint associated with an innovative input. Costs of adjusting the input are due to the risk & uncertainty associated its use. Eventually, as time progresses, the consuming firms will become comfortable with the performance of these inputs through learning by using and the risk and uncertainty associated with them will diminish. Consequently, the demand for these "once innovative" inputs will be governed by the factors specified by the studies noted earlier; namely, factor prices, technology and scale effects.

If in fact a firm employs an input that is costly to adjust and/or the demand for the input is partly determined by its level of acceptance, then empirical models which do not account for these possibilities are likely to yield biased results since they are misspecified. Misspecification can have great repercussions on the models forecasting and policy simulation ability. But perhaps more importantly, in a misspecified model the actual interpretation of the estimated coefficients may be nebulous since the variables included in the model will be capturing the effects of the important explanatory variables excluded from the model.

Two empirical studies of innovative forest products have, to some extent, recognized the static nature of the traditional approaches discussed above. In an analysis of the derived demand for softwood plywood and lumber in the U.S., Spelter (1984, 1985) drew upon the diffusion theory of market penetration. Spelter postulated that product demand is influenced by the market behavior of competing innovative products, among other factors. He maintains that technologies and

innovations reach market maturity following an S-shaped curve from the time of introduction until they saturate the market. In turn, Spelter argued that the estimates of price elasticity from his model are more accurate than estimates from traditional frameworks since his approach incorporates the influence of technologies and innovations.

The other study was conducted by Singh, Samama and Nautiyal (1988). They modeled the demand for NSP in Canada as a function of both economic and market (i.e., degree of consumer awareness about the product) factors. In the spirit of diffusion theory, the authors used a second-degree polynomial growth function as a proxy for the market factors affecting demand for NSP. Again, as in Spelter's work, the obvious advantage of this study over traditional approaches is that it incorporates the theory of diffusion.

The two studies presented above have demonstrated the importance of incorporating the theory of product diffusion into demand models. However, an important weakness of these models is that they are not firmly grounded in microeconomic theory. Both studies ignore important variables and the models are not explicitly derived from a theoretical framework that represents the underlying production structure and the optimizing behavior of the consuming industry.

## 1.2 OVERVIEW OF NSP PRODUCTS AND THE NSP INDUSTRY

The term NSP covers an array of products - homogeneous waferboard, layered waferboard, partially oriented waferboard and oriented strandboard (Haygreen et al., 1985). The recent emergence of NSP products was the result of innovation and productivity changes in the

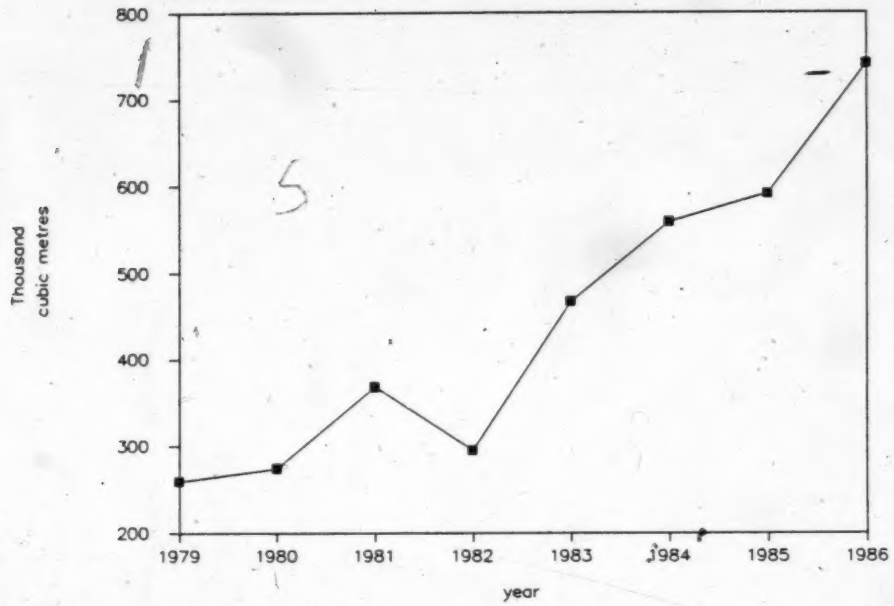
North American products industry over the last few decades. The first waferboard plants were built in the United States and Hudson Bay, Saskatchewan in 1955 and 1961, respectively. It was not until the mid 1970s that the next plant was built. By the early 1980s the first oriented strandboard mills in North America were in operation. Today, there are approximately 24 NSP mills in the U.S. and 13 operating in Canada (RISI, 1987).

Since the late 1970s, the diffusion of the technology in North America to produce NSP products has been very rapid. Consumption of NSP products has also increased in the last decade. As illustrated in Figure 1, Canada consumed approximately 259,172 cubic metres of NSP in 1979 which rose substantially to 740,888 cubic metres in 1986. A similar pattern is evident for the United States (Figure 2) (A rise from 513,242 M3 in 1979 to 3,690,037 m3 in 1986).

The ability of NSP products to compete with existing wood products, namely softwood plywood, in a variety of applications is demonstrated by the rapid increase in market share of the structural panel market, which is defined to include softwood plywood and NSP. This is illustrated in Figures 3, and 4.

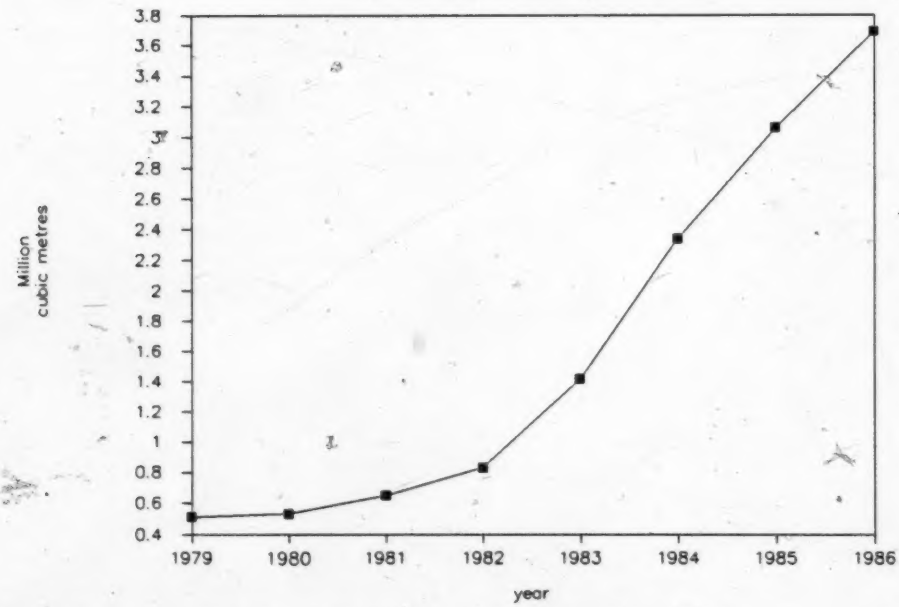
The impressive growth in consumption of these products can be attributed to both physical and economic advantages NSP products have over softwood plywood. The physical advantages include (Gall, 1980): (1) Superior appearance - unlike softwood plywood, NSP products do not have any visible defects (i.e., knots, delaminations, etc.); (2) NSP products can be produced in larger sheets compared to plywood which makes them attractive in the construction of mobile homes and factory

**Figure 1: Total Domestic Consumption Of NSP Products In Canada**



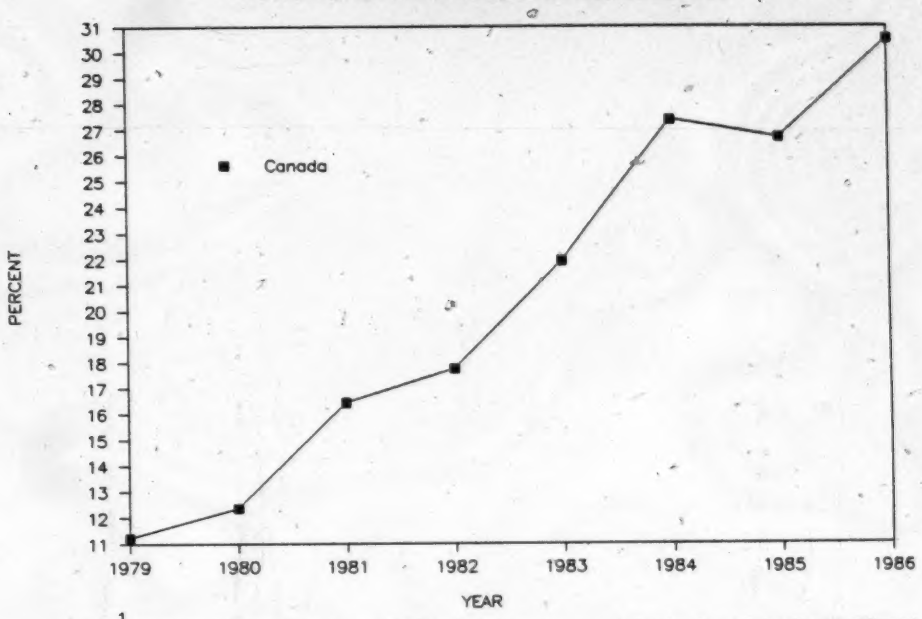

Adapted from Statistics Canada catalogue 36-003

**Figure 2: Total Domestic Consumption Of NSP Products In The United States**



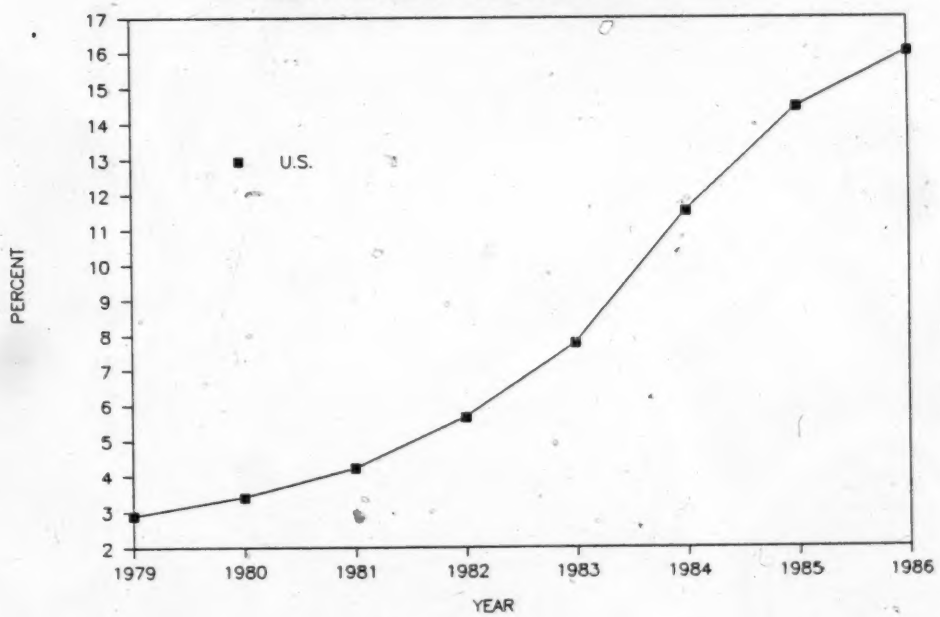

Adapted from Resource Information Systems Inc. (RISI)

**Figure 3: Percent Share Of NSP Products In The Canadian Structural Panel Market[1]**




[1]The structural panel market is defined to include non-veneered structural wood panels and softwood plywood.

**Figure 4: Percent Share Of NSP Products In[1] The United States Structural Panel Market**




[1]The structural panel market is defined to include non-veneered structural wood panels and softwood plywood.

built houses.

NSP has cost advantages over softwood plywood for several reasons. The aspen resource from which most NSP is manufactured is relatively under-utilized, hence stumpage prices for these species are low. Furthermore, since there is an abundance of aspen, NSP producers are able to locate their mills close to both the resource and the markets; this helps producers save on transportation costs. Another cost advantage is that, since aspen reproduces asexually, regeneration costs are insignificant. Finally, the technology to produce NSP is more automated than softwood plywood mills, thus labor costs are lower (Booth, 1986). The combination of these cost factors has allowed NSP producers to sell their product at a price much lower than the price for softwood plywood.[2]

There are, however, two factors that have worked against the growth of NSP products. The first factor, one that is long-term in nature, is that NSP products are heavier than softwood plywood which is a disadvantage from a transportation and the construction workers point of view (Gall, 1980). The second, and perhaps the most serious of the two at least in the short-term, is the risk and uncertainty associated with these products. Since plywood has been used extensively in the construction industry for many years, construction firms have become

---

[2] In 1986 gross variable costs for Western Douglas fir sheathing plywood were $144 per 1000 sq.ft. (3/8" basis), with delivered wood costs and labor costs accounting for $70 and $40 per 1000 sq.ft. (3/8" basis), respectively. For U.S. North Central oriented strandboard, however, gross variable costs were only $81.68 per 1000 sq.ft. (3/8" basis) with delivered wood costs and labor costs accounting for $27.19 and $13.11 per 1000 sq.ft. (3/8" basis), respectively. (RISI, 1987).

confident with its performance in many applications. As a result, it becomes rather difficult for NSP products to penetrate end-use markets dominated by plywood. Nonetheless, as time progresses, these products will be more accepted as firms become more comfortable with their performance. Presumably, therefore, the effects of this latter determinant on the growth of NSP products will diminish as time progresses.

## 1.3 OBJECTIVES AND OUTLINE OF THE THESIS

It is evident that the static neoclassical approaches to modeling the derived demand for forest products are inadequate for innovative forest products since they fail to account for an adjustment behavior, and, although they have improved on the adjustment component, the dynamic formulations developed by Spelter (1984, 1985) and Singh et al. (1988) are unsupported by a strong theoretical base. Given this, the focus of this thesis is to develop an econometric model of the demand for NSP products by the Canadian and U.S. construction industries that combines the neoclassical theories of derived demand with the models commonly employed in diffusion research (e.g. those employed by Spelter and Singh et al.). The alternative demand models proposed in the literature will be tested against this more general model. Finally the chosen model will be used to examine the market penetration of NSP and its economic relationship to other inputs used in the construction industry. This latter objective will include testing to see if NSP is an innovative forest product in Canada and the United States.

To this end, the remainder of this thesis is outlined as follows.

In Chapter 2, a discussion of the theory of product innovations is presented. This involves both a theoretical and empirical survey of the innovations literature. In Chapter 3, the neoclassical theory of the firm and duality theory, which provides the underlying framework for this study, is briefly discussed. Two alternative solutions to the problem of modeling demand for new products are presented. The stochastic specification and appropriate tests for these models are outlined in Chapter 4 while the results of the final models chosen are presented in Chapter 5. Some conclusions, caveats and areas for further research are outlined in Chapter 7. Finally, a detailed description of the data used in the study is given in Appendix 1, and some further results are shown in Appendix 2.

# Chapter 2

# DIFFUSION OF INNOVATIONS

Economists have recognized the importance of technological change to productivity and economic growth for many years now. Most empirical studies in this area have concentrated on measuring changes in output and productivity that stem from the introduction of a new technology. More recently, however, economists have been equally concerned with measuring the diffusion of technology since the economic impact of a technological change depends on the speed at which it is diffused (Rosegger, 1980). That is, a firm will adopt an innovation as a means of advancing towards its ultimate goal of profit maximization (or cost minimization) but the impact the innovation has on the industry will depend on the rate at which it is diffused within firms and across firms. Hence, the diffusion process is one of the basis for economic growth. The purpose of this chapter is, therefore, to present a general overview of the established theories of diffusion and some of the empirical studies on the diffusion process.

## 2.1 AN OVERVIEW

### 2.1.1 THE DIFFUSION PROCESS - A CONCEPTUAL PERSPECTIVE

Technological change has been described by Mansfield (1968) as

> "the advance of technology, such advance often taking the form of new methods of producing existing products, new designs which enable the production of products with important new characteristics, and new techniques of organization, market and management."

The process of technological change can be divided into three

stages: Invention, Innovation and Diffusion (Davies, 1979). The diffusion stage, which is of interest in this study, occurs when the adoption of the new product or process proceeds from its initial to its final, or long-run equilibrium, level of adoption. During this stage, the innovation is recognized as being superior to existing, competing technologies. In other words, the diffusion stage is the process by which the use of the innovation spreads and grows (Mansfield et al., 1971).

A unimodal frequency distribution of adopters arranged on a time scale has been used to statistically describe the diffusion process (Stoneman, 1983). As can be seen in Figure 5, this distribution has been divided into a five category scheme that is based on the individuals' innovativeness.[3] Integrating this distribution results in an S-shaped curve which represents a cumulative distribution of adoption (Figure 6). Several functional forms, some of which are discussed later on in this chapter, have been used to represent the S-shaped process. But irrespective of the actual form used, many researchers suggest that the diffusion process is characterized by three phases: introduction, expanding, and maturing phase. After maturity, the product(s) may go through a declining phase if superior, succeeding innovations arise.

In the introduction stage, the rate of diffusion of the innovation is slow and variable, which may be due to several factors

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[3]Innovativeness has been defined by Rogers & Shoemaker (1971) as "the degree to which an individual is relatively earlier in adopting new ideas than other members of the system."

Figures 5 and 6 have been removed because of the unavailability of copyright permission. These figures illustrated the adopter categories and s-shaped curve contained on pages 182 and 177, respectively of Rogers & Shoemaker (1971).

(Rosenberg, 1976). First of all, some firms or individuals may delay their use of an innovation in anticipation of further improvements in the innovation or decline in its price. Second, in order to employ an innovation, the development and learning of new skills may be required. A third factor is that innovations are often interdependent, thus until the complementary innovation is developed diffusion will be slow. An example of this latter factor is that, if an investment in new capital is required in order to use the innovation, diffusion of the innovation may be slow since most capital cannot be easily installed in the short-term. Adoption can also be delayed if there is limited information regarding the availability, cost and performance of the innovation. Finally, institutional developments, or lack there of, can often slow down the rate of diffusion of an innovation. Therefore, in addition to the price of the innovation, there are costs of adjusting the level of use of a recently adopted innovation.

During the expanding phase, the market penetration of the innovation increases rapidly as the innovation becomes accepted, as economies of scale are achieved, as improvements in the production process occur, as more information is available and as the "learning process" diminishes (Stern et al., 1975). The slope of this phase will vary depending on the rate of acceptance of the innovation.

Eventually, as the innovation becomes readily accepted by its users, the growth rate of diffusion begins to decline. This event marks the beginning of the maturing phase which is also referred to as the ultimate (long-run) equilibrium or ceiling of the diffusion process. In some empirical studies the long-run ceiling has been restricted to

remain constant over time. However, the ceiling may shift in response to factors such as changes in the quality of the technology, the introduction of substitutes, shifts in the demand for the industry's output, or lower prices which stem from economies of scale in production (Lakhani, 1975).

The underlying basis for diffusion theory, according to the theoretical exposition above, is to rationalize why a superior innovation is not immediately adopted by all potential users. Empirical researchers, on the other hand, have focused on measuring the diffusion process and identifying which factors govern the diffusion of an innovation. Some of the more popular diffusion models are the topic of the next subsection.

### 2.1.2 THE DIFFUSION PROCESS - AN EMPIRICAL PERSPECTIVE

Several functional forms have been used to quantify the diffusion process (S-shaped curve); namely the logistic, Gompertz, cumulative lognormal, and the modified exponential. Because these functional forms are easy to implement and generate a sigmoid diffusion pattern, they have been widely used in diffusion research. However, in many of the studies employing these forms two restrictive assumptions have been implied.

First of all, many authors have implicitly assumed that time adequately accounts for all explanatory variables important to the diffusion process. Typically, as Griliches (1980) noted, time is brought in as a proxy for (1) declining real costs of the technology due to cumulative improvements and learning by doing (or using); (2)

the scrapping of old durable equipment, making way for the new; and (3) risk reduction due to the spread of information about the operating characteristics, workability and profitability of the new technology. A second assumption, which was mentioned previously, is that the long-run ceiling remains constant over time.

Using the above approach a smooth S-shaped curve emerges. This is unrealistic since, even though the average trend is typically S-shaped, the observed diffusion process is irregular in shape. This is because the diffusion process is governed by many explanatory variables, not just time. As a result, the explanatory and forecasting ability of this model is inadequate when the researcher is not only interested in the general trend but also in mapping the fluctuations around the mean. The second assumption - a constant ceiling - is highly unrealistic since it assumes that there has been no post-innovation improvements and that the adoption potential is fixed (Thirtle & Ruttan, 1987, p. 97).

The above approaches were pioneered by Griliches (1957) for hybrid corn and Mansfield (1961) for twelve innovations in the United States and then later employed by many other researchers.[4] Despite the weaknesses in their approaches, these works have provided useful insights into the knowledge on diffusion and to the development of improved models.

The fundamental difficulties in the earlier attempts to model diffusion resulted in a proliferation of alternative methodologies. One of the more prominent approaches to emerge was to view the diffusion

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[4]See, for instance, Fisher & Pry (1971), Blackman (1974), Buongiorno & Oliveira (1977), and Bengston (1984).

process as a function of economic variables and not just time. Also, in many studies, this included endogenizing the ultimate long-run equilibrium; making it a function of economic variables. Rather than describing a disequilibrium adjustment process approaching a constant ceiling of diffusion, this framework would allow the system to adjust to the values of explanatory variables at each point in time, thus representing an equilibrium system in the long-run (Thirtle & Ruttan, 1987, p. 109). This approach results in a "product growth curve" that is an envelope of successive diffusion curves, which simultaneously accounts for product improvements and a shifting long-run potential (ibid, pp. 97-98).

Recently, one of the more commonly employed models of the aforementioned approach has been the stock adjustment model. This model can be expressed as:

(1) $\log n_t - \log n_{t-1} = \beta(\log N^* - \log n_t)$

The general idea behind this model is that the growth in use of a technology at any moment in time is proportional to the difference between the actual stock ($n_t$) and the desired equilibrium stock ($N^*$) (ibid, p. 100). The growth rate of diffusion of a new technology ($n_t - n_{t-1}$) depends directly and proportionally on the speed of adjustment ($\beta$) of the actual stock to the equilibrium stock.

Chow (1967) rationalized the use of the stock adjustment model for analyzing the diffusion process by suggesting that the growth rate of diffusion depends on the existing stock of technology - a proxy for the level of acceptance of the technology - and the difference between the equilibrium level and existing stock which accounts for the number

of prospective adopters remaining. These arguments provide a conceptual linkage between the stock adjustment model and the diffusion process. In addition to the conceptual relationship, Chow demonstrated that there exists an empirical linkage between the S-shaped diffusion process and the stock adjustment model.[5] Finally, another attractive attribute of this model is that $N^*$ can be made a function of economic variables thus allowing for a ceiling that is responsive to changes in the economic environment. Consequently, because of these appealing features, the stock adjustment approach has received much attention from diffusion researchers.[6]

A slightly alternative approach to the one described above was introduced by Stoneman (1983, pp. 115-17). In his approach, it is assumed that the firm will choose a level of new technology ($n_t$) so as to maximize its profits subject to the underlying production technology and the cost of employing the new technology. Stoneman argued that, because of the cost of adjusting the level of a new technology, the amount invested in the innovation at any point in time will only be

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[5]Chow (1967, p. 1118) demonstrated that the logistic and Gompertz curves can be expressed as the following two differential equations:

(1) $\frac{dn_t}{dt} = \beta n_t (N_t - n_t)$ (logistic); and

(2) $\frac{dn_t}{dt} = \beta n_t (\log N_t - \log n_t)$ (Gompertz)

[6]Some of the other studies employing the stock adjustment model include; Stoneman (1976) in the diffusion of computers, Lakhani (1975) in studying the diffusion of environment-saving techniques used in petroleum refineries, and Stier (1983) for analyzing technological substitution in the United States pulp and paper industry.

some proportion of the difference between $N^*$ and $n_t$ which, as expressed above, is the basic concept underlying the stock adjustment model. Clearly then, in Stoneman's model, the stock adjustment mechanism is used to represent adjustment costs. Moreover, like the model developed by Chow, Stoneman's (1983) approach reveals a logistic diffusion curve and the long-run potential (ceiling) is a function of economic variables. Stoneman's approach is more appealing than Chow's model in that the speed of adjustment ($\beta$) is dependent on the adjustment costs thus it is endogenous and time varying rather than exogenous and fixed. However, since this approach requires more data (more variables) than the simple stock adjustment model, it has not been extensively used in diffusion studies.

So far, the focus of this chapter has been to introduce the idea that there are costs to adjusting the use of an innovative product or process and to review some of the empirical approaches that account for these costs.[7] As will become apparent in the next chapter, this review on diffusion will be used to develop alternative approaches to modeling the demand for NSP products. Before proceeding into the next chapter, however, a conceptual representation of the impact of a new innovation on the consuming firm(s) and industry is given.

## 2.2 THE ECONOMIC IMPACT OF A TECHNOLOGICAL CHANGE

The introduction and diffusion of an innovation is one means of

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[7]It is worth pointing out that the theoretical and empirical models of diffusion presented in this chapter can be used to model and explain the diffusion of an innovation within a region or between regions.

economic growth. A new process technology will create an outward shift in the marginal cost (MC) curve of the individual firm (Stoneman, 1983, pp. 151-152). Since in this conceptual framework the producer is assumed to be a price-taker, the firm will increase its output in order to satisfy the profit maximizing condition MC = price (p) (refer to Figure 7). This result is contingent on the assumptions that the firm is a profit maximizer (or cost minimizer) operating in a perfectly competitive industry and that all other things remain unchanged.

To demonstrate the impact of a technology on the adopting industry, it is assumed that the industry being analyzed is comprised of two firms with identical production technologies (same MC curves).[8] The marginal cost curves of the two firms and the industry's supply curves and market demand curves are illustrated in Figure 8.

Now suppose firm 1 adopts a new technology but firm 2 remains a non-adopter. Firm 1's MC curve will shift out (MC1' to MC1'') which in turn will create an outward shift in the industry's supply curve (from So to S1). Subsequently, there is an increase in the industry's output (Q' to Q'') and a decline in output price (from Po to P1). At the new price, firm 1's output level will be higher than it was before the innovation was adopted (q1'''>q1''), but firm 2 (non-adopter) will produce less than it did before the innovation was introduced to the

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[8]The industry's supply curve is the sum of the portion of each individual's marginal cost curve that extends above its average variable cost curve. Even though the individual firms are price takers, the industry as a whole is capable of influencing output price.

**Figure 7: A Conceptual Representation Of The Impact Of A Technology On An Individual Firm.**

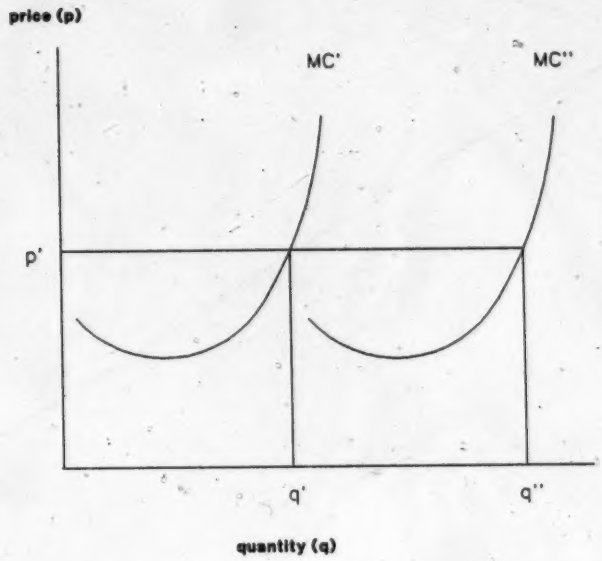
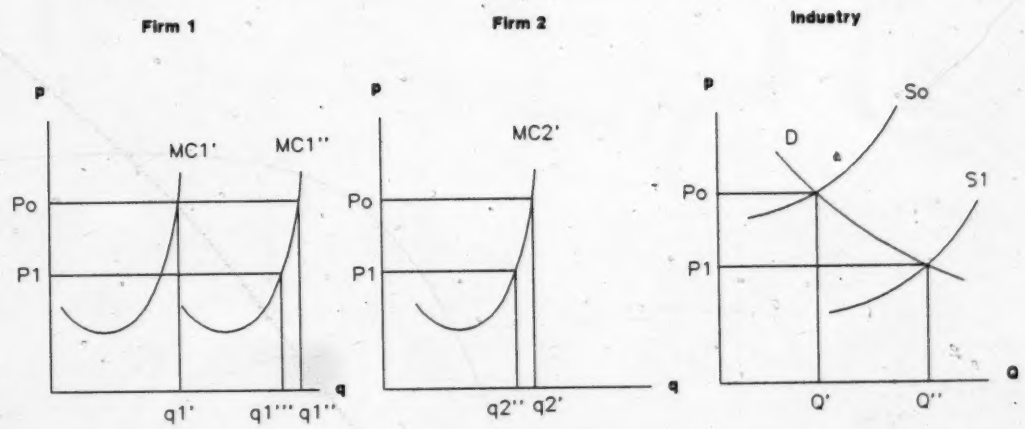



**Figure 8: A Conceptual Representation Of The Impact Of A Technology On A Industry**



industry ($q2'' < q2'$).[9]

The industry analysis can be extended to include several firms however the results are similar; as the technology diffuses within the industry (i.e., as more and more firms adopt) each adopting firms' output will increase resulting in an increase in the total industry output. If market demand remains unchanged then output price will decline thus forcing non-adopters to produce less output than they did before the innovation was introduced.

In summary, the ultimate aim of this thesis is not to explicitly measure the impact of a new technology (NSP) on the construction industry or to identify and measure the economic variables governing the diffusion of NSP products but rather to adopt an approach that incorporates the adjustment process associated with most innovations; that is, adopt a more completely specified model of innovation demand. Such an approach will then allow factor demands and elasticities of substitution between inputs that account for the adjustment process to be derived and the market penetration of NSP products to be examined. Moreover, the hypothesis that NSP is an innovative forest product can be tested with such an approach.

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[9]For a detailed conceptual mathematical presentation of the impact of a technological change on an individual firm and the industry see Stoneman (1983).

# Chapter 3
# THEORETICAL MODELS

This chapter proposes two alternative solutions to the problem of modeling the demand for innovative forest products. In both approaches, the dual cost function is adopted as the underlying theoretical structure and to reflect the optimizing behavior of the firm. Before introducing these alternative formulations, a brief discussion of duality theory and the specification of the dual cost function and its corresponding factor demand equations is given.

## 3.1 NEOCLASSICAL THEORY OF THE FIRM

### 3.1.1 COST MINIMIZATION

This study focuses on the demand for wood products used in residential, repairs & alterations and non-residential construction. In both Canada and the United States, these are the principal consuming sectors of wood panel and lumber products.

It is assumed that the technology of both the Canadian and U.S. construction industries can be represented through a production function relating output (Q) to the services of six inputs: non-veneered structural wood panels (N), particleboard (PT), plywood (P), lumber (L), "other" building materials (O), and a homogeneous labor-capital input (LK).[10] This can be expressed as:

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[10]Labor and capital have been combined into one input in this thesis in order to reduce the number of parameters to be estimated in the econometric models. This is explained in more detail in Chapter 4 and Appendix 1.

(2) $Q = f(x_N, x_{PT}, x_P, x_L, x_O, x_{LK})$

where $x_N, x_{PT}, x_P, x_L, x_O, x_{LK}$ are the input quantities.

Shephard (1953, 1970) has shown that under certain "regularity conditions" a firm's production technology can be accurately represented by a production function or, alternatively, by a dual cost function. In the context of this study, a conceptual dual cost function, which specifies the least cost of producing a single output, can be defined as:

(3) $C(r,Q) = \min\{r'x: f(x) \geq Q\}$

where $C(r,Q)$ is the total cost function for the construction industry, $r$ is an $n \times 1$ vector of exogenous input prices, and $f(x)$ is the production function. In many studies technology is also included in the cost function as an proxy for technical change; however, this variable is not addressed until Chapter 4.

In order for duality to exist, both the production and cost functions must satisfy certain regularity conditions. The conditions the production function must satisfy are (Diewert, 1982, p. 553):

(P1) $f(x)>0 \ \forall x>>0$ ($f$ is positive)[11]

(P2) $G(Q) \equiv \{x: f(x) \geq Q\}$ is a convex set $\forall Q$ in the range $f$ ($f$ is a quasi-concave function)

Moreover, the cost function must fulfill the following regularity conditions (ibid, 1982, p. 554):

(C1) $C(Q,r) \geq 0 \ \forall r, \ Q \geq 0$ (non-negativity)

(C2) $r_1 > r_0$ implies $C(Q,r_1) \geq C(Q,r_0)$ (increasing in r)

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[11] $\forall$ is defined as "for all".

(C3) $Q_1 > Q_0$ implies $C(Q_1, r) \geq C(Q_0, r)$ (increasing in Q)

(C4) $C(\lambda, Q, r) = \lambda C(Q, r)$ (linear homogeneous in prices)

(C5) $C(Q, r)$ is concave in input prices r $\forall Q$ (implies cost minimizing behavior)

(C6) $C(Q, r)$ is continuous in $r, Q$ $\forall r, Q$.

A cost function is used to represent the industry since it has been commonly used in previous studies of forest products demand and hence the results of this study will be directly comparable with those in the literature.[12] Thus, the conceptual model in (3) will be the heart of this analysis.

### 3.1.2 FACTOR DEMAND EQUATIONS

Applying Shephard's Lemma (Shephard, 1953, 1970), the cost-minimizing factor inputs are easily obtained by differentiating the cost function in (3) with respect to input price ($r_i$). The resulting equations are expressed as:

(4) $X_i(Q, r) = \partial C(Q, r) / \partial r_i$; $\quad i = N, PT, P, L, O, LK$

It should be clear that, since the system of demand equations in (4) were explicitly derived from (3), (4) can also be used to represent the underlying production technology of the industry. Consequently, most of the characteristics of the production technology that are obtainable from the cost function can also be recovered from the system of factor demand equations (i.e., elasticities of substitution,

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[12] Some of the studies that have used Shephard's Duality Theorem to model the demand for solid wood products are Doran & Williams (1982), Rockel & Buongiorno (1982), and Sharma (1986).

homotheticity, etc.).

The above discussion and most studies employing duality theory are based on the assumption that, in response to economic shocks, factor inputs are adjusted instantaneously to their optimal long-run levels at each point in time. However, because it has been argued that there are certain costs inherent in NSP products that discourage rapid adjustment, this assumption may not be appropriate for analyzing the construction industry. Incorrectly imposing the restrictive assumption of instantaneous adjustment in equation (4) could lead to biased estimates. Thus this restriction must be tested in the context of more general and dynamic specifications of equation (4).

## 3.2 COMPETING METHODOLOGIES

### 3.2.1 ADJUSTMENT COSTS OF INNOVATIVE PRODUCTS

It was emphasized earlier that most innovations are not immediately adopted by all potential users. With regard to NSP products and the construction industry, there are several reasons why this argument may be valid. For instance, firms may be discouraged to make an instantaneous adjustment of NSP products if they are operating in an atmosphere of risk and uncertainty. This type of situation could arise when a firm is unfamiliar with the properties and performance of NSP products in certain construction applications, and consequently is not willing to employ the less expensive innovation at the risk of losing existing and future customers or at the risk of being liable for a poorly constructed building project. Even if firms are comfortable with the performance of NSP, they may have to develop new skills in order to

employ NSP. Also, before a firm uses NSP, it must study and understand any building codes that pertain to these products.

It is quite clear from the considerations made above that, when adjusting the use of NSP, the construction industry may face certain costs. As a result, a firm may be reluctant to immediately adjust its use of NSP to the long-run cost minimizing bundle irrespective of the price advantage NSP has over more established products. Moreover, as long as NSP is sluggish to adjust in the short-run, other inputs must over adjust since the factor demands are interdependent (Woodland, 1976, p. 57). Nevertheless, the adjustment costs associated with NSP will diminish over time as the consuming firm becomes complacent with the performance of these products.

### 3.2.2 PARTIAL ADJUSTMENT MODEL

Several econometric approaches have been developed that integrate adjustment costs into the neoclassical theory of the firm. One of the most commonly applied approaches has been the partial adjustment model (PAM) which may be expressed as follows:

$$(5)\quad X_{it} - X_{it-1} = \phi_{ij}\left[X^{*}_{it} - X_{it-1}\right] \qquad (i,j = N,PT,P,L,O,LK)$$

where $X_{it}$ is the quantity of input $i$ consumed in period $t$; $X_{it-1}$ is the quantity of input $i$ consumed in period $t-1$; $X^{*}_{it}$ is the long-run desired quantity of input $i$ in period $t$[13]; and $\phi_{ij}$ are the own- and cross-partial adjustment coefficients.

The neoclassical theory can be explicitly incorporated in this

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[13]Throughout this study, an asterisk after a variable indicates that it pertains to the long-run and is unobservable.

model via the variable $X^{*}_{it}$. It can be recalled from section 3.1.2 that the factor demand equations derived from the static dual cost function represent the long-run equilibrium level of demand. It follows, therefore, that:

(6) $X^{*}_{it} = X_{it}(Q_t, r_t)$

Rearranging equation (5) and substituting in equation (6) the actual factor demands in time period t are:

(7) $X_{it} = \phi_{ij}\left[X_{it}(Q_t, r_t)\right] + (1-\phi_{ij})X_{t-1}$

Hence, if $\phi_{ij} = 1 \; \forall ij$ then $X_{it} = X^{*}_{it}$ which is the comparative static model outlined in Chapter 3.

The partial adjustment framework has a number of desirable features which makes it superior to the traditional static approach and the models employed by Spelter (1984, 1985) and Singh et al. (1988). First, the approach implicitly accommodates for the existence of adjustment costs which influence the rate at which NSP products are adopted.

Second, the stock adjustment model (SAM) presented in Chapter 2 and the partial adjustment model are very similar in terms of the adjustment process.[14] Thus the conceptual linkage between the SAM and diffusion theory noted by Chow (1967) can also be applied to this model (refer to section 2.1.2).

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[14]Many authors do not distinguish between the stock adjustment and partial adjustment model. However, the stock adjustment used by Chow (1967) (refer to Chapter 2) and the partial adjustment used here differ in that lagged input quantity ($n_{t-1}$) rather than current input quantity ($n_t$) enters the partial adjustment model. Nonetheless, these two models are conceptually very similar.

Finally, this approach can be viewed as an improvement over the single-equation SAM used in diffusion theory because it allows for interrelated demands and is firmly grounded in the microeconomic theory of the firm; the long-run demand levels in the PAM are explicitly derived from the underlying production structure of the firm whereas in most diffusion studies employing the SAM the long-run levels are a function of GNP and output prices.

The partial adjustment model defined in (7) was first introduced to address the assumption that the actual capital stock converges on the desired capital level with a lag. The adjustment lag between actual and desired capital stock levels arises for several reasons. Because of its quasi-fixed nature, physical capital may be difficult to adjust immediately in response to a economic shock. In turn, any input that is complementary to capital (i.e., some forms of energy) will also be difficult to adjust immediately in the short-run (Berndt, Morrison & Watkins, 1981). Finally, a firm may adjust some factor inputs with a lag if it perceives the economic stimuli to be temporary (Mohr, 1980) and/or if there are costs involved in obtaining the information required to make an immediate adjustment decision (Anderson & Blundell, 1982).

It was suggested above that the optimal use of NSP will approach the long-run level as the product becomes accepted overtime (i.e., as the adjustment costs diminish), ceteris paribus. The optimal use of primary inputs like capital will, however, rest primarily on the firms perception of the permanency of the change in output and how fixed these inputs are in the short-run. In contrast to NSP products, the

adjustment costs inherent in most primary inputs are likely to remain constant overtime because of their physical nature. Clearly then, the behavior of a firm towards innovative inputs like NSP is conceptually different than its behavior towards quasi-fixed inputs such as capital.

There have been a number of studies of factor demand, factor substitution and production technology that have employed the partial adjustment approach. Some of these works include Nadiri & Rosen (1969), Mohr (1980), Norsworthy & Harper (1981), Heimler & Milana (1986), Nautiyal & Singh (1986), Singh & Nautiyal (1986) and Meil et al. (1988). All of these authors have used the aforementioned arguments (i.e., quasi-fixity of capital, information costs, etc.) to justify the use of this dynamic approach. To date, however, no study has attempted to use this approach for analyzing the firm's or industry's decision behavior towards innovative inputs.

It is possible that the partial adjustment approach is a reasonable model of behavior because of quasi-fixity in capital, labor or the other inputs, and not because of innovativeness in NSP.[15] Fortunately the cause of the adjustment mechanism can be identified by examining the individual adjustment coefficients.[16] Therefore, not only can the existence of dynamic behavior in the industry be tested for

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[15]Another factor that may govern the demand for an input in the short-run is changes in the level of factor input inventories that are held by the producing industry. However, since inventory data for the construction industry are not readily available, it is not possible to include an inventory variable in the model and to determine if inventory adjustments are in fact causing dynamic behavior.

[16]It will become apparent in Chapter 4 that the choice of functional form is important for determining if the adjustment process can be identified via the adjustment coefficients.

with this model, but the factor(s) causing the adjustment process can be identified as well. This is discussed in greater detail in Chapter 4.

An alternative and more formal method for testing the hypothesis that adjustment behavior in the construction industry is the result of the innovative nature of NSP products would be to endogenously model the adjustment parameter $\beta$ (i.e., test to see if $\beta$ is a function of variables such as the number of existing adopters, number of potential adopters, levels of advertisement, etc.). Several approaches that allow for an endogenous adjustment parameter have been developed. The model developed by Stoneman (1983) (refer to Chapter 2) is one approach to the problem. Also, Berndt, Morrison & Watkins (1981) discuss an approach for explicitly incorporating costs of adjustment for quasi-fixed factors.[17] Unfortunately these specifications require sophisticated non-linear estimation procedures and also are very data intensive and were not used in this study.

### 3.2.3 LOGISTIC APPROACH

The final, competing approach explored in this thesis for measuring the derived demand for innovative products is a logistic model incorporating the long-run input demands derived from the dual cost function. This approach is an improvement over the static dual cost function and Spelter's (1984, 1985) and Singh et al.'s (1988)

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[17]These models are commonly referred to as third generation dynamic models. They have been applied empirically by Berndt, Fuss & Waverman (1979), Denny, Fuss & Waverman (1980) and Merrifield & Singleton (1986), and reviewed and assessed by Berndt, Morrison & Watkins (1980).

approaches in that it accounts for any adjustment costs that may exist and is well embodied by the theory of the firm.

In diffusion research the logistic model has been widely used since it produces the familiar S-shaped growth pattern displayed by many innovations. For the purpose of modeling innovation demand, the logistic curve may be expressed as:

$$(8) \qquad X_{it} = \frac{N}{1 + a_1 \exp^{(-a_2 t)}}$$

where: $X_{it}$ is the consumption of product $X_i$ in period t; N is the maximum (long-run) demand level the product can reach; t is a constant incremental time trend; and $a_1$ and $a_2$ are the parameters to be estimated.

This simple trend fitting model is consistent with the increased consumption of NSP products overtime as the evidence in Chapter 1 indicates. However, this approach is ad hoc in nature and lacks any microeconomic foundations.

Spelter (1984, 1985) improved on the simple logistic model by incorporating prices into the formulation via the time trend. However, he treated the ceiling as exogenous, thus implicitly assuming that there were no product improvements or changes in the number of potential adopters over the products life cycle. In addition, Spelter did not explicitly derive the demand equations from the underlying production technology of the consuming industry.

To improve on the basic logistic model and the work conducted by Spelter, a combined model of the logistic equation in (8) and the long-run demand equations derived from the dual cost function is

employed. The long-run demands are incorporated into the logistic model via the specification of the long-run level of demand - N. Hence, the long-run equilibrium demand is a function of input prices and output demand instead of remaining constant over time. This model may be expressed as follows:

$$(9) \quad X_{it} = \frac{X_{it}(Q_t, r_t)}{1 + a_1 \exp^{(-a_2 t)}}$$

In this study it is assumed that the single time trend t in equation (9) adequately captures the short-run behavior of the using industry towards the input $X_i$. Ideally, this variable would be replaced by relative prices and market factors such as the availability of information to the user and the level of acceptance (a proxy for learning by using). However, since the short-run behavior is determined primarily by market factors that are unobservable, especially for new products, this behavior can be adequately represented by the logistic time trend (McKillop & Wibe, 1987, p. 309).

The approach defined in (9) offers theoretical improvements over the approach introduced by Spelter since the long-run levels are explicitly derived from the production technology of the using industry and the long-run ceiling is endogenized. There are, however, some minor empirical limitations to the formulation expressed in equation (9) which are addressed more in the next chapter.

In summary, the logistic approach described above seems to be another promising alternative for measuring the derived demand for innovative forest products. In this thesis this approach will be

compared with the traditional long-run static model as well as the partial adjustment approach described above. The "best" model will be selected based on several statistical and theoretical tests. The empirical and stochastic specification of each model and the appropriate tests are outlined in the next chapter.

# Chapter 4

# MODEL SPECIFICATION AND TESTS

Three approaches for measuring the demand for innovative inputs and the substitution possibilities between inputs were presented in the preceding chapter. This chapter reviews the specification of each model, the data used in estimation, and the test procedures for choosing among the competing models.

## 4.1 EMPIRICAL SPECIFICATIONS

### 4.1.1 CHOICE OF FUNCTIONAL FORM

The actual production technology of the industry is often unknown *a priori*. Several authors have attempted to distinguish between the performance of various functional forms but in many of these studies the results were inconclusive. Consequently, based on Woodland (1976, p. 15), the choice of a functional form for use in this analysis will depend on two criteria. In order to minimize the prior assumptions imposed on the model, the functional form selected should be capable of depicting a wide range of production technologies; and second, the researcher should be able to estimate and interpret the empirical model defined by the functional form with minimal effort.

With regard to the first criteria, it logically follows that a functional form from the family of "flexible" forms should be used.[18]

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[18]Functional forms that are capable of providing a second order approximation in input prices to an arbitrary continuously differentiable cost function are referred to as "flexible" functional forms (Woodland, 1976, p. 20).

These forms place no priori restrictions on the elasticity of substitution between inputs or on the structural characteristics of the production technology (i.e., homotheticity, returns to scale, etc.). Nevertheless, relying solely on this criterion only effectively narrows the possible selection slightly since several "flexible" functional forms are available. The more commonly recognized "flexible" forms include: Translog (TL), Generalized Cobb-Douglas (GCD), Generalized Leontief (GL), Generalized Quadratic (GQ), Generalized McFadden (GM) and Generalized Barnett (GB). Therefore, from this group, the second criterion is applied in order to select a functional form for this research.

Diewert and Wales (1985) have shown that the GM and GB maintain global concavity while still satisfying flexibility in prices.[19] This is an attractive feature, however these forms are highly non-linear hence costly to compute. As a result, neither of these forms are adopted in this study. Another specification that is not considered here is the GQ. Although the theoretical underpinnings of the GQ are well-developed it has been used relatively little in empirical applications, thus its performance has not been compared with the more popular GL and TL forms.

The factor demand equations can be obtained from either one of the remaining functional forms. However, predicted costs are required in

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[19]It has been shown by Hazilla & Kropp (1984) and Diewert & Wales (1985) that global concavity can be imposed on some of the more conventional functional forms; namely, the Translog and Generalized Leontief. However, the restrictions proposed by these authors are very costly to impose thus are not considered here.

order to retrieve the demand equations from the TL or GCD since, via Shephard's Lemma, these forms yield share equations and not demand equations like the GL. Unfortunately, the cost function (and in turn predicted costs) cannot be conveniently estimated in this study. First of all, there is an insufficient number of observations to estimate all the parameters of the cost function. Second, it is difficult to specify a cost function that is consistent with the partial adjustment and logistic demand equations outlined in Chapter 3.

Another limitation with the TL and GCD functional form when used in a partial adjustment framework is that the true interpretation of the adjustment parameters ($\phi_{ij}$) becomes ambiguous. This is because, when one of the share equations from the system of equations is dropped to satisfy the adding-up condition, the adjustment coefficients associated with the deleted equation must be subtracted from the remaining adjustment coefficients. These coefficients then lose their true meaning since "we have no information to identify any of the individual elements $\phi_{ij}$" (Mohr, 1980, p. 151).[20] In addition, the factor inputs causing the adjustment process, if one exists, cannot be identified using the TL or GCD. Accordingly then, given the shortcomings of the other forms for the purpose of this study, the Generalized Leontief (Diewert, 1971) is the functional form employed here.

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[20]Refer to Mohr (1980, pp. 150-151) for a detailed explanation of this argument.

### 4.1.2 STATIC LONG-RUN EQUILIBRIUM COST FUNCTION

Following Lopez (1980), the six input - single output homothetic, constant returns to scale GL cost function of the construction industry can be represented as:

$$(10)\quad C(r,Q,t) = Q\sum_{i}^{6}\sum_{j}^{6} b_{ij} r_i^{1/2} r_j^{1/2} + Qt\sum_{i}^{6} \gamma_i r_i$$

where $r_i$ (or $r_j$) is the price of input $i$ (or $j$) ($i,j$=N, PT, P, L, O, LK);[21] Q is industry output; t stands for time; and $b_{ij}$, $\alpha_i$, and $\gamma_i$ are the parameters to be estimated.

Because of data unavailability, industry output had to be constructed by dividing total industry expenditures, a proxy for total industry costs, by the price of output. Using total expenditures as a proxy for total costs implies that in the long-run economic profits in the industry are zero. Thus, in the long-run the perfectly competitive construction industry, which is comprised of price taking firms that can freely enter or exit the industry, can produce any output simply by doubling all inputs; hence the marginal costs (MC) and average costs (AC) are constant over all levels of output (Woodland, 1976, p. 23). This is the assumption of constant returns to scale (linear homogeneity in output) which was imposed on all models in order to maintain consistency between the data and the models.[22] This assumption is

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[21] N is non-veneered structural wood panels; PT is particleboard; P is plywood; L is lumber; O is other building materials; LK is labor/capital.

[22] Another property of production that is commonly tested for is homotheticity. A production function is homothetic if it can be expressed as a monotonic increasing function of a homogeneous function (Henderson & Quandt, 1980, p. 106). Thus all homogeneous functions are homothetic.

discussed in more detail in Appendix 1.

Applying Shephard's Lemma to (10) and dividing by industry output (Q) yields the following cost minimizing input/output demand equations ($a^{*}_{ij}$):

$$(11) \quad a^{*}_{it} = X_{it}/Q_{t} = \sum_{j}^{6} b_{ij}\frac{(r_{jt})^{1/2}}{(r_{it})^{1/2}} + \gamma_{i}t$$

The reason for deriving input/output demand equations rather than input demand equations is given later on in this chapter.

It was noted in Chapter 3 that, in order for duality to exist between the cost function and production function, the input/output demand equations in (11) must satisfy certain regularity conditions. The only regularity conditions that are imposed *a priori* on the system of input/output demand equations in (11) are linear homogeneity in prices and continuity; these conditions are inherent in the GL functional form. The remaining regularity conditions will be checked; these checks are discussed in section 4.4.2. Furthermore, satisfying Young's theorem and conserving the number of estimated parameters, symmetry ($b_{ij} = b_{ji}$) is imposed *a priori*.[23]

### 4.1.3 DYNAMIC PARTIAL ADJUSTMENT MODEL

The specification of the input/output demand equations for the partial adjustment model defined in (7) of Chapter 3 are expressed as

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[23]Young's Theorem states that the cross partial derivatives for a given function will always be equal if both cross partials are continuous. Therefore, since the GL function is continuous by definition, symmetry must hold.

follows:

(12) $a_{it} = \phi_{ij} a^{*}_{it} + (1-\phi_{ij}) a_{it-1}$

where $a^{*}_{it}$ are the long-run input/output demands from (11); $a_{it}$ are actual (observed) input/output demands; and $\phi_{ij}$ are the own- and cross-adjustment parameters.

Expressing (12) in matrix form yields the following system of six interrelated GL input/output factor demand equations:

(13)

$$\begin{bmatrix} a_{Nt} \\ a_{PTt} \\ a_{Pt} \\ a_{Lt} \\ a_{Ot} \\ a_{LKt} \end{bmatrix} = \begin{bmatrix} \phi_{NN} & \phi_{NPT} & \phi_{NP} & \phi_{NL} & \phi_{NO} & \phi_{NLK} \\ \phi_{PTN} & \phi_{PTPT} & \phi_{PTP} & \phi_{PTL} & \phi_{PTO} & \phi_{PTLK} \\ \phi_{PN} & \phi_{PPT} & \phi_{PP} & \phi_{PL} & \phi_{PO} & \phi_{PLK} \\ \phi_{LN} & \phi_{LPT} & \phi_{LP} & \phi_{LL} & \phi_{LO} & \phi_{LLK} \\ \phi_{ON} & \phi_{OPT} & \phi_{OP} & \phi_{OL} & \phi_{OO} & \phi_{OLK} \\ \phi_{LKN} & \phi_{LKPT} & \phi_{LKP} & \phi_{LKL} & \phi_{LKO} & \phi_{LKLK} \end{bmatrix} X$$

$$\begin{bmatrix} a^{*}_{Nt} - a_{Nt-1} \\ a^{*}_{PTt} - a_{PTt-1} \\ a^{*}_{Pt} - a_{Pt-1} \\ a^{*}_{Lt} - a_{Lt-1} \\ a^{*}_{Ot} - a_{Ot-1} \\ a^{*}_{LKt} - a_{LKt-1} \end{bmatrix} + \begin{bmatrix} a_{Nt-1} \\ a_{PTt-1} \\ a_{Pt-1} \\ a_{Lt-1} \\ a_{Ot-1} \\ a_{LKt-1} \end{bmatrix}$$

The static model defined in (11) is "nested" within the dynamic partial adjustment model in (13), thus the regularity conditions outlined in Chapter 3 must also apply to the long-run component of the model in (13).

No restrictions (e.g. symmetry) are imposed on the adjustment component of the model since the equations from (13) have not been derived from a short-run cost function. Moreover, as Anderson & Blundell (1982) pointed out, "In the short-run we are not assuming

that agents are in equilibrium and therefore there seems no reason why short-run behavior should satisfy any such restrictions" (p. 1563).[24]

### 4.1.4 THE LOGISTIC APPROACH

The final approach explored in this study is the logistic model. This formulation combines the logistic function commonly employed in diffusion theory with the long-run input/output demand equations outlined in equation (11). This model is specified as:

$$(14) \quad a_{it} = \frac{a^{*}_{it}}{1+c_i \exp^{(d_i t)}}$$

The structure in (14) only captures the growth and maturation phase of a product's life cycle and does not account for the possibility of a declining phase. As a result, the formulation in (14) is not sufficient for measuring the derived demand for existing, well established inputs such as lumber and plywood. An alternative form, other than the logistic, could have been employed in an attempt to capture both the growth and declining stages; but because of the limited resources and the scope of this study, no effort is made to pursue that course here. Consequently, only the input/output demand of NSP products will be estimated in this study.

The specification in (14) is subject to the same regularity conditions as the partial adjustment model; once more, linear

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[24]This approach is consistent with other studies using this framework. See, for example, Mohr (1980), Norsworthy & Harper (1980), Anderson & Blundell (1982), Nautiyal & Singh (1986), Singh & Nautiyal (1986) and Meil et al (1988).

homogeneity in prices and continuity are maintained hypotheses while the rest will be checked. Additionally, analogous to the partial adjustment framework, no restrictions are imposed on the adjustment coefficients, $c_N$ & $d_N$, and symmetry is not imposed in the short-run.

### 4.1.5 STRUCTURAL INFORMATION

A great deal of information about the production structure of the construction industry can be obtained from the models proposed above once the parameters are estimated. The measures used to summarize this information are discussed next.

#### 4.1.5.1 Elasticities of Demand

Own-price elasticities are numerical indexes measuring the percent change in demand for input $i$ in response to a percent change in the price of input $i$. This measure is easily obtained by differentiating the input/output demand equations ($a_i^*$) with respect to input price ($r_i$) and then multiplying by $\frac{r_i}{a_i^*}$. For the GL system of input/output demand equations in (11), the long-run own-price elasticities ($E_{ii}^L$) are calculated as follows (Diewert, 1971):

$$(15)\quad E_{ii}^L = \frac{-Q}{2a_i^*} \sum_j b_{ij} \left( \frac{r_j}{r_i} \right)^{1/2}, \quad i \neq j, i, j = n, t, p, l, o, k$$

where $a_i^*$ are the long-run predicted input/output demands. Equation (15) can be used to calculate the long-run own-price elasticities for all three models (static (11), partial adjustment (13), logistic (14)). According to economic theory, the own-price elasticities for each of the inputs should be negative.

Cross-price elasticities are numerical indexes measuring the percent change in demand for input $i$ in response to a percentage change in the price of input $j$. For all three models, the long-run cross-price elasticities ($E^L_{ij}$) are calculated by differentiating $a^*_i$ with respect to $r_j$ and then multiplying by $\frac{r_j}{a_i}$. For the GL input/output demand equations, the long-run cross price elasticities are calculated as follows:

$$(16) \quad E^L_{ij} = \frac{1}{2a^*_i} b_{ij} \left(\frac{r_j}{r_i}\right)^{1/2} \quad , \; i \neq j, \; i,j = N, PT, P, L, O, LK$$

Cross-price elasticities are useful measures for determining the substitution or complementary relationship between inputs. If the cross-price elasticity between two inputs is positive then the inputs are substitutes; if it is negative they are complements.

Since the adjustment equations from this model are not explicitly derived from a dynamic economic optimizing cost function, that is, a short-run cost function is not specified, it is difficult to define short-run elasticities that satisfy the *Le Chatelier-Samuelson* principle[25] (Berndt, Morrison & Watkins, 1980, p. 14). Consequently, even though short-run elasticities could be derived from the equations in (13), their economic meaning would be inconsistent with the neoclassical theories of the firm. Instead of short-run elasticities, simulations of short-run responses of demand to economic shocks can be

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[25]The *Le Chatelier - Samuelson* principle proves that, since the long-run cost function provides an envelope relationship to the short-run cost function and both cost functions are concave, long-run derived demand is more own-price elastic than short-run derived demand (Chambers, 1988, pp. 102-105).

done with these models.

#### 4.1.5.2 Elasticities of Substitution

Another useful instrument for measuring the relationship between inputs is the elasticity of substitution ($\sigma_{ij}$). It is defined as the proportionate rate of change of the input ratio divided by the proportionate rate of change of the rate of technical substitution (Henderson & Quandt, 1980, p. 73). Thus it is a measure of the ease at which inputs substitute (or alternatively, complement) each other in the production process while output is held constant.

Following the definition of elasticity of substitution for the cost function set out by Uzawa (1964), the Hick-Allen elasticity of substitution for the Generalized Leontief cost function can be computed simply as:

(17) $\sigma_{ij} = \frac{E_{ij}}{S_j}$ where $\sigma_{ij} = \sigma_{ji}$ is the partial elasticity of substitution between input $i$ and input $j$; $S_j$ is the cost share of input $j$; and $E_{ij}$ is the cross price elasticity between input $i$ and input $j$. When $\sigma_{ij}$ is positive, factors $i$ and $j$ are considered substitutes; when it is negative they are complements.

#### 4.1.5.3 Technical Change

In a neoclassical setting, technical change is the reduction in one or more inputs required to produce a given level of output, or equivalently, an increase in output from the same quantities of inputs that results from the introduction of a new technology or an increase in the stock of knowledge used in production (Thirtle & Ruttan, 1987, p. 12). If a new technology leaves the factor proportions unchanged (a

homothetic shift) then the technical change is said to be Hicks-neutral. However, if the relative factor proportions are not equally affected, then the technical change is said to be Hicks-biased (Hicks, 1963).

One of the most popular variables used to measure technical change in production economics is a simple time trend. This variable was incorporated into the long-run input/output demand equations in (11); $\gamma_i$ is the technical change coefficient for input $i$. Inclusion of this variable into the model allows the nature of technical progress in the construction industry over the study period to be examined. The technical change is said to be (Hicks, 1963):

(a) factor $i$ saving if $\gamma_i<0$ (the marginal rate of technical substitution (MRTS) of $i$ for $j$ declines over time);

(b) factor $i$ using if $\gamma_i>0$ (MRTS of $i$ for $j$ increases over time);

(c) factor neutral if $\gamma_i=0$ (MRTS of $i$ for $j$ remains unchanged over time).

One of the main weaknesses of using time as a proxy for technical progress is that it is not always clear what exactly is being measured. However, for the purpose of this research it is assumed that the time trend captures the effects of disembodied technical change.[26]

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[26]Disembodied technical change can be referred to as improvements in the planning organization, coordination and control of productive activities whereas embodied technical change refers to change in the physical inputs employed in the production process (Rosegger, 1980, p. 17).

#### 4.1.5.4 Adjustment Coefficients

##### 4.1.5.4.1 Partial Adjustment Model

Despite the number of studies that have employed the combined dual cost function - partial adjustment approach, very few theoretical ground rules regarding the *a priori* expectations of the values of the adjustment coefficients ($\phi_{ij}$) have been established. Most studies have focused only on separating the actual (short-run) behavior from the desired (long-run) behavior and for the most part have ignored the signs and sizes of the adjustment coefficients. However, in this study, the characteristics of the adjustment coefficients are instrumental for examining the market penetration of NSP, which is the main thrust of this research. Interpretation of the adjustment parameters will also prove useful for assessing the model and data set, and for comparing demand responses between countries.

The conceptual idea behind the partial adjustment model is that the adjustment of input $i$ to its desired level depends on the gap between the desired and actual levels for that input and the other inputs. This concept in general form was represented as follows:

$$(18)\quad a_{it} = \sum_{\substack{j=1 \\ j\neq i}}^{6} \phi_{ij}(a^{*}_{jt} - a_{j,t-1}) + (1-\phi_{ii})a_{i,t-1} + \phi_{ii}a^{*}_{it}$$

Referring to equation (18), if $(a^{*}_{jt}-a_{j,t-1}) > 0$ ($< 0$) then "excess demand" ("excess supply") for that input exists. Consequently, a positive cross adjustment coefficient ($\phi_{ij}$) would suggest that the using industry would increase its short-run demand for input $i$ in

response to the "excess demand" for input $i$. The opposite scenario would prevail if the adjustment coefficient was negative (i.e., "excess demand" of factor $j$ would induce the using industry to lower its demand for input $i$).

Given the considerations made above, the smaller the absolute value of the cross-adjustment coefficient, the less effect an incomplete adjustment in the factor market $j$ will have on the demand for input $i$.

Several points with regards to the own-adjustment coefficients ($\phi_{ii}$) can be made as well. A $\phi_{ii}$ equal to unity signifies that the using industry instantaneously adjusts its use of that input to its long-run desired level. However, it must be remembered that incomplete adjustment in the other factor markets can also influence the demand for input $i$. Evidentially then, if all $\phi_{ii} = 1$ and all $\phi_{ij} = 0$ the firm would immediately adjust all inputs to their long-run desired levels in response to a economic stimuli. In other words the traditional static model would be appropriate for modeling the behavior of this industry.

An own-adjustment coefficient less than unity suggest that adjustment costs do exist for that input. The smaller the own-adjustment coefficient, the higher the adjustment costs. An $\phi_{ii}$ greater than unity, on the other hand, indicates that the firm over adjusts that input in response to an economic stimuli thus that input is quite easy to employ in the short-run. Therefore, the inputs influencing the adjustment process can be determined by examining these coefficients. Finally, there are no theoretical explanations for a negative own-adjustment coefficient hence such a result may indicate

that the model or data needs to be reassessed.

#### 4.1.5.4.2 Logistic Model

The adjustment process in the logistic model is governed by the sizes and signs of $c_t$ and $d_i.t$ in (14). It is clear that, as $\exp^{-d_i t}$ approaches zero and $c_t$ is small in size, the actual input/output demand for NSP products approaches the desired long-run input/output demand levels ($a_i^*$). That is, the input can be adjusted to its long-run levels without incurring any considerable adjustment costs.

## 4.2 DATA DESCRIPTION

A general description of the data used to estimate the proposed models is given here. Data sources and major details of the construction of the data are left to Appendix 1.

The data to be used in estimation are quarterly data from the third quarter in 1979 to the fourth quarter in 1986 for Canada and the United States. The data required included output of the construction industry, which accounts for residential, repairs & alterations and nonresidential construction, prices of NSP, particleboard, plywood, lumber, "other" building materials, labor and capital,[27] and the quantity demanded for the seven inputs by the construction industry.

For Canada, the quantity and price data for NSP, particleboard and plywood are measured in cubic metres and dollars/cubic metres, respectively whereas the remaining variables are in index form since

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[27]Nominal prices were used.

they were made up of more than one good.[28] The Tornqvist method was used to index these inputs. The data for the United States are measured in the same units as the Canadian data except lumber is in cubic metres and dollars/cubic metres. Finally, for both countries, labor and capital were aggregated into one input using the Tornqvist index in order to reduce the number of parameters to be estimated, and the output data are in index form.[29]

## 4.3 STOCHASTIC SPECIFICATION AND ESTIMATION METHODS

Three competing formulations for modeling the demand for NSP have been put forth in this study. In order to estimate these models, it is assumed that the observed factor input/output demands are distributed stochastically around the cost-minimizing input bundles. This involves appending a disturbance or error term ($e_t$) to each of the equations in (11), (13) and (14).

In most single-equation regression models, it is assumed that the error terms have the following properties:

1. $E(e_{it})=0$ for all $i$; and
2. $E(e_{it}\, e_{jt}) = \begin{cases} 0 & i \neq j \text{ all } i,j \\ \sigma_{ij}^2 & i=j \text{ all } i,j \end{cases}$

where $\sigma_{ij}^2$ is the variance of the estimator. That is, the error terms are assumed to be normally distributed with a mean of zero, be homoscedastic (have a constant variance over time), be nonautocorrelated and have zero correlation with the error terms across

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[28]For instance, the "other" building materials input includes wall board, asphalt shingles, etc..

[29]None of the data were seasonally adjusted.

equations.

It is believed, however, that the construction industry jointly chooses input quantities to minimize input cost. This implies that the error terms are jointly distributed (non-zero correlation across equations ($E(e_{it}\ e_{jt})\neq 0$)).

A final comment concerning the error terms is that the reason input/output demand equations were used instead of demand equations to formulate the models in this thesis was to reduce the problem of heteroscedasticity. This approach is consistent with other studies employing the GL functional form (see, Parks (1971), Lopez (1980), Lopez & Tung (1982) and Diewert & Wales (1985))[30], and hence is maintained throughout this study.

The procedure used to estimate the parameters of the static long-run model defined in (11) is Zellner's iterative seemingly unrelated regression (SUR) method (Zellner, 1962). This procedure is a maximum likelihood method, so long as the system converges, and it accounts for contemporaneous correlation in the error terms (Christensen & Greene, 1976, p. 663).

In order to retrieve the parameters from the interrelated dynamic system defined in (13), the system was estimated using the non-linear iterative maximum likelihood technique. Like Zellner's SUR, this procedure accounts for contemporaneous correlation in the error terms.

Finally, the single equation, logistic model was also estimated using the non-linear iterative maximum likelihood technique. It must be

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[30]Parks (1971, pp. 131-132) provides a detailed explanation of this approach.

kept in mind that by estimating only the demand for NSP products, some loss in efficiency of the estimated parameters may occur since this procedure does not incorporate information from the other input/output demand equations (i.e., it assumed that there is zero correlation between disturbance terms of the demand system). At any rate, this approach still appears to be a promising alternative for modeling the derived demand for innovative inputs.[31]

Before the models were estimated, a final issue was taken into account. In order to realize consistent estimators[32] of the parameters using the two techniques mentioned above, it must be assumed that the independent variables are exogenous and thus uncorrelated with the error terms. In this study this assumption is unrealistic since industry data are being used and the principal consumer of the six inputs is the construction industry. Thus it is likely that a change in the industry's output would influence the price of each input. As a result, the factor prices will be correlated with the error terms resulting in inconsistent estimators.

To address this problem, the method of instrumental variables was used.[33] The predicted prices from regressing the observed input prices

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[31]The econometrics computer program SHAZAM was used to estimate all of the models in this study. For the static models, the convergence level was set at the default level of .001. The default method was used for estimating all non-linear models. Also, for the non-linear models, the *numeric* option was used and the convergence level was set at the default of .00001. Refer to White & Horsman, 1986 for further details.

[32]If the estimated parameter is asymptotically unbiased and the variance of the estimator approaches zero as the sample size increases then the estimator is said to be consistent (Koutsoyiannis, 1977, p. 108).

[33]Refer to Appendix 2 for a complete discussion of this topic and a list of the instruments and results from this study.

on a set of instruments were used in estimation. It is assumed that the instruments chosen were correlated with the dependent variable but not with the disturbance terms, therefore the estimated parameters are consistent.

## 4.4 TEST PROCEDURES

### 4.4.1 SPECIFICATION TESTS

The three competing models must be statistically tested against one another in order to determine which specification provides the "best" representation of the industry. This not only involves testing these models against each other but also testing more restricted models against the formulations defined above. This is achieved by using two sets of tests.

#### 4.4.1.1 Nested Tests

There are two groups of models specified in this study; system of equations and single-equation models. Each group is comprised of models that are "nested" within each other.

The partial adjustment system of input/output demand equations and the long-run static system of equations are contained in the first group. The partial adjustment model that allows for Hicks biased technical change is the most general, unrestricted model in this group. This model is defined in 13.

By imposing successive parameter restrictions on the general model in (13), three more restrictive models emerge. In a increasingly restrictive order, these models are as follows:

(iii) Hicks-neutral technical change is imposed on the general form,

which implies:

$$\gamma_i = 0 \quad \forall\, i$$

(1iii) Instantaneous adjustment is imposed; however Hicks-biased technical change is restored. This implies the following restrictions on the general form:

$$\phi_{ii} = 1 \;\forall\, i; \quad \phi_{ij} = 0 \;\forall\, i,j \quad i \neq j$$

This model is the static long-run model in (11).

(1iv) Instantaneous adjustment as well as Hicks-neutral technical change is imposed on the general model.

$$\phi_{ii} = 1 \;\forall\, i; \quad \phi_{ij} = 0 \;\forall\, i,j \quad i \neq j; \quad \gamma_i = 0 \quad \forall\, i$$

The second group includes two specifications of the single equation logistic model and two specifications of the single equation static long-run model. These models are tested separately from the models in group 1 since they are only estimated for NSP products and because the logistic model is not "nested" within the partial adjustment model, or visa versa. The most general, unrestricted model from this group is the logistic model with time as an explanatory variable. This is the model defined in (14). The models tested against this model are as follows:

(2ii) Hicks-neutral disembodied technical change is imposed:

$$\gamma_i = 0 \quad \forall\, i$$

(2iii) Instantaneous adjustment is imposed but Hicks-biased technical change is restored. This implies the following constraints on the general model:

$$c_N \exp^{(d_N)} = 0$$

(2iv) Instantaneous adjustment and Hicks-neutral technical change are

imposed:

$$c_N \exp^{(d_N)} = 0; \quad \gamma_i = 0 \quad \forall i$$

The most appropriate technique for implementing the test outlined above is the likelihood ratio (LR) procedure (Harvey, 1981, p. 163). According to this procedure, once all of the models have been estimated, the likelihood functions from each of the restricted model are individually compared with the more general model using the following LR formula:

(19) $LR = -2ln\lambda = 2lnL(\psi_1) - 2lnL(\psi_0)$

where: $\lambda = L(\psi_0)/L(\psi_1)$ where $\lambda$ should be <1; $L(\psi_1)$ is the value of the likelihood function of the unrestricted general model; $L(\psi_0)$ is the value of the likelihood function of the restricted model; and *ln* is the natural logarithm.

Using this procedure, the null hypothesis ($H_o$) relates to the restricted model whereas the alternative hypothesis ($H_1$) is that the unrestricted model "best" describes the industry. This test statistic is distributed $\chi^2_m$ where m is the number of restrictions in $H_o$ (Harvey, 1981, p. 163). Hence, $H_o$ is rejected if the LR≥ the critical $\chi^2_m$ at a specified level of confidence. In this study, a 95% level of confidence will be used.

**4.4.1.2 Non-nested Tests**

The models that are derived from the two groups after performing the LR test procedure will be compared using a "non-nested" test procedure.

Four of the most widely used "non-nested" tests are the Cox-Pesaran-Deaton (or CPD) test (Pesaran & Deaton, 1978) and the J, C

and P tests (Davidson & MacKinnon, 1981). Except for the C test, however, these techniques are arduous to implement especially when comparing a model from a system of equations with a single equation model.[34] Hence, the C test is the approach adopted here.

The C test can be expressed as follows:

(20) $a_N = \alpha_0 + (1-\alpha_1)\hat{f}_1 + \alpha_1\hat{g}_1 + \varepsilon_1$

where $a_N$ is the actual input/output demands for NSP; $\hat{f}_1$ are the predicted values for NSP input/output demand from the model selected from the first group; $\hat{g}_1$ are the predicted values for input/output demands for NSP from the model selected from the second group; and $\alpha_0$ and $\alpha_1$ are the estimated parameters.

Clearly then, if $H_0$ refers to the model from the first group and $H_1$ corresponds to the model from the second group, the formulation from group one provides the "best" specification of the industry if $\alpha_1$ is not significantly different from zero. The significance of $\alpha_1$ at a 95% confidence level can be tested using the conventional asymptotic t test.

The test procedures presented above for selecting a final model for each country are also demonstrated in Figure 9.

### 4.4.2 REGULARITY CONDITIONS

Monotonicity in prices and concavity in prices are the two

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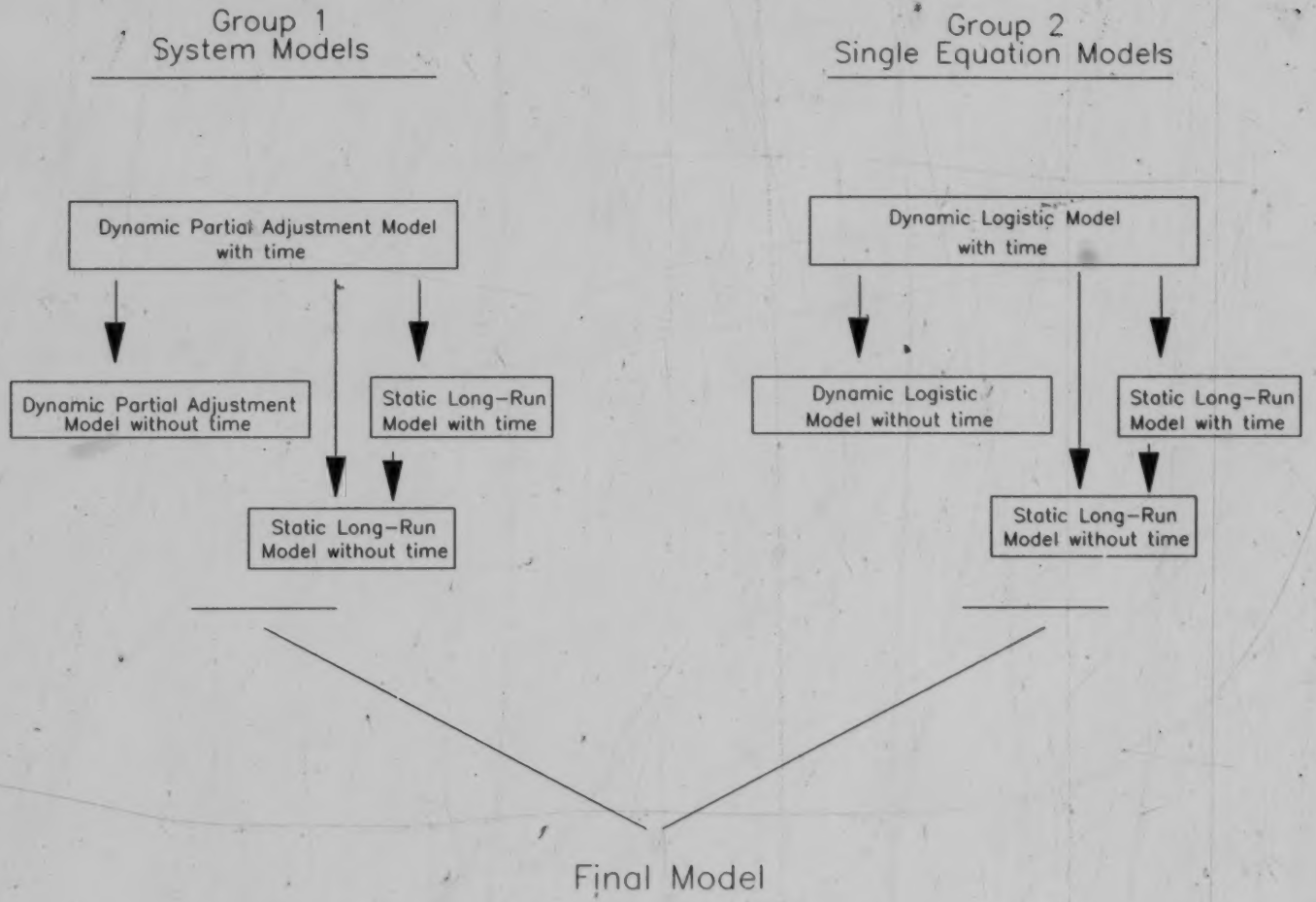
[34] In using the J or P test, the models being compared must be estimated concurrently.

**Figure 9: A Diagrammatic View Of The Specification Test Strategies.**


Group 1
System Models
Group 2
Single Equation Models
Dynamic Partial Adjustment Model with time
Dynamic Partial Adjustment Model without time
Static Long-Run Model with time
Static Long-Run Model without time
Dynamic Logistic Model with time
Dynamic Logistic Model without time
Static Long-Run Model with time
Static Long-Run Model without time
Final Model

regularity conditions tested in these thesis.[35] The monotonicity in price condition is satisfied if $\partial C/\partial r_i > 0$ for all $i$ at each observation (Lopez, 1980). This clearly implies that the estimated input/output demand values must be positive at each observation. In the case of the dynamic models, this condition must only be satisfied in the long-run since cost-minimization is not explicitly modeled in the short-run.

One of most commonly violated conditions in empirical work on production economics is concavity. Rejection of this assumption casts doubts on the assumption that all producers in the industry exhibit cost-minimizing behavior. Several authors have introduced methods for imposing concavity *a priori*,[36] however these approaches are highly non-linear and costly to compute thus are not investigated in this analysis. As a result, concavity in prices will be checked in this thesis.

Concavity is satisfied if the Hessian matrix (of second-order partial derivatives with respect to input prices) is negative semi-definite. The sign-definiteness of the Hessian can be checked using either the determinantal test or characteristic root test (eigenvalues test) (Chiang, 1984, pp. 320-330). The latter test is employed here since it allows both the necessary and sufficient

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[35]Linear homogeneity in prices and continuity were the only two regularity conditions imposed on the models. Since the cost function is not being estimated, however, non-negativity in costs (condition C3) will not be tested. Additionally, since linear homogeneity in output is imposed, quantity monotonicity (condition C5) will not be tested.

[36]Refer to Footnote 21.

conditions for concavity to be checked simultaneously, whereas the determinantal test does not (ibid, p. 330).

In this study concavity will be checked at each observation point for the final models only. This will be done by computing the eigenvalues for the Hessian matrix at each sample point. If all eigenvalues are nonpositive then the Hessian is negative semi-definite at that sample point (in other words it satisfies concavity) (ibid, p. 330). The implications of violations of this condition at one or more sample points will be discussed in Chapter 5.

### 4.4.3 MISSPECIFICATION TESTS

In section 4.3 several assumptions regarding the properties of the disturbance terms were made; namely that they were non-autocorrelated, homoscedastic, normally distributed, and contemporaneous correlated. Departure of the disturbance terms from these assumptions could destroy the optimal properties of the estimation technique. For instance, violation of non-autocorrelation or homoscedasticity could lead to "unbiased but inefficient estimation and invalid inference procedures" (Johnston, 1984, p. 310). Moreover, the statistical reliability of the t-ratio test becomes suspect if normality does not hold (Koutsoyiannis, 1977, p. 197). Finally, a violation of contemporaneous correlation implies that no efficiency gains were made by using SUR instead of Ordinary Least Squares (OLS). In consequence, the properties of the disturbance term should be investigated in order to assess the reliability of the model.

The departure of the error terms from the assumptions can be

examined by various tests. In this study, however, only autocorrelation and non-randomness of the error terms will be examined. This is because non-normality does not affect asymptotic inference tests, which are used in this research, to any great degree (Judge et al., 1985, p. 824), the tests for heteroscedasticity are quite burdensome to invoke, especially for systems of equations, and the violation of contemporaneous correlation is innocuous.

Autocorrelation will be tested using the Durbin-Watson test procedure. This procedure is sufficient for testing autocorrelation in the static and logistic models but it is inadequate for testing autocorrelation in the demand equations of the partial adjustment model since lagged values are part of the explanatory variables. Instead, the Durbin-Watson h test is used for the partial adjustment model.[37] The specific form of this test is not presented here but is discussed by Johnston (1984, p. 318).

The Runs test will be used to test for the existence of non-random (i.e., autocorrelated or heteroscedastic) error terms (refer to Gujarati, 1977, p. 206).

The tests described above will only be performed on the final model. Also, if autocorrelation or non-randomness is present in the final model, there will be no attempt to correct for these problems in this thesis; nevertheless, the results and hypothesis tests will be

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[37]As Johnston (1984, p. 318) points out, since the assumption of a nonstochastic matrix of the independent variables required for the Durbin-Watson test is defied when the lagged dependant variables are part of the explanatory variables, the Durbin-Watson h test must be used.

interpreted accordingly.

# Chapter 5

# MODEL SELECTION AND FINAL RESULTS

This chapter reviews the performance of the models discussed previously. The organization of this chapter is as follows. First, the specification test results for each of the models estimated are presented. Based on these results, a final model representing the construction industry in each country is selected. Second, a detailed presentation and discussion of the results from the final models is given. This includes a discussion of the results from the regularity checks, misspecification tests, and structural tests.

## 5.1 SPECIFICATION TESTS

### 5.1.1 CANADIAN CONSTRUCTION INDUSTRY

The likelihood ratio (LR) tests for the models in group 1 and group 2 for the Canadian construction industry are reported in Tables 1 and 2, respectively. The LR ratios indicate that all of the restrictions imposed on the most general, unrestricted model - the partial adjustment model with Hicks biased technical change - are rejected at the 95% level of significance. This implies that, over the study period, the Canadian construction industry has been unable to adjust factor demands instantaneously to long-run equilibrium levels, and that the dynamic model is improved through the inclusion of biased technical change.

The LR ratios from group 2 (Table 2) indicates an entirely different result. None of the null hypotheses can be rejected at the

**Table 1: Specification Test Results From The Models In Group 1, Canadian Construction Industry.**

| Model Number[1] | Log of Likelihood Function | Hypothesis[2]/ Likelihood Ratio | Number of Restrictions | Critical $\chi^2_m$ (95%) | Test Outcome |
|---|---|---|---|---|---|
| 1 | 14.8344 | – | none | – | – |
| 2 | 5.1167 | (a) 19.44 | 6 | 12.59 | reject $H_o$ |
| 3 | -48.5390 | (b) 126.75 | 36 | 50.96 | reject $H_o$ |
| 4 | -95.0714 | (c) 219.81 | 42 | 58.11 | reject $H_o$ |

[1] Model 1 is the dynamic partial adjustment model with technical bias
Model 2 is the dynamic partial adjustment model without technical bias
Model 3 is the static, long-run model with technical bias
Model 4 is the static, long-run model without technical bias

[2] $H_o$ in (a) is that Model 2 is not statistically different from Model 1.
$H_o$ in (b) is that Model 3 is not statistically different from Model 1.
$H_o$ in (c) is that Model 4 is not statistically different from Model 1.

**Table 2: Specification Test Results From The Models In Group 2, Canadian Construction Industry.[1]**

| Model Number[2] | Log of Likelihood Function | Hypothesis[3]/ Likelihood Ratio | Number of Restrictions | Critical $\chi^2_m$ (95%) | Test Outcome |
|---|---|---|---|---|---|
| 1 | -60.5499 | – | none | – | – |
| 2 | -61.4691 | (a) 1.84 | 1 | 3.84 | do not reject $H_o$ |
| 3 | -62.2214 | (b) 3.34 | 2 | 5.99 | do not reject $H_o$ |
| 4 | -63.0015 | (c) 4.90 | 3 | 7.81 | do not reject $H_o$ |

[1] It should be remembered that these tests were performed on the NSP input/output demand equations only.

[2] Model 1 is the dynamic logistic model with technical bias
Model 2 is the dynamic logistic model without technical bias
Model 3 is the static, long-run model with technical bias
Model 4 is the static, long-run model without technical bias

[3] $H_o$ in (a) is that Model 2 is not statistically different from Model 1.
$H_o$ in (b) is that Model 3 is not statistically different from Model 1.
$H_o$ in (c) is that Model 4 is not statistically different from Model 1.

95% significance level which implies that the most restrictive single-equation model with no technical bias represents the Canadian construction industry as well as the less restrictive formulations in group 2. This suggests that the construction industry does behave in a static manner and has not witnessed significant biased technical change over the study period.

Given these two conflicting specifications, it is necessary to formally test which of these two models "best" represents the production technology and economic behavior of the using industry. This is accomplished by invoking the "non-nested" C-test. The null hypothesis ($H_o$) in this test is that the partial adjustment model with time is the most appropriate specification of the Canadian construction industry.

The results from the C-test, which are reported in Table 3, clearly show that $\alpha$ is not significantly different from zero at the 95% level of significance. It can be concluded that the partial adjustment model with time provides the "best" specification of the Canadian construction industry and thus is the final model adopted in this study.[38]

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[38]The restricted static model from group 2 was estimated for NSP only which the reader should keep in mind when assessing this result. A different test result may have emerged if the models from group 2 could have been estimated as a system.

Table 3: Specification Results From The "Non-Nested"[1] C-Test, Canadian and U.S. Construction Industries.

| | $\alpha_1$ | | $\alpha_0$ | |
|---|---|---|---|---|
| Industry | Estimate | T-ratio | Estimate | T-ratio |
| Canadian | 0.1477 | 1.1081 | 0.0268 | 0.1302 |
| United States | 0.2805 | 1.5614 | 0.0099 | 0.0550 |

[1] The estimated equation is $a_N=\alpha_0 + (1-\alpha_1)\hat{f}_N + \alpha_N\hat{g}_N$ where $\hat{f}_N$ and $\hat{g}_N$ are the predicted input/output demand values for NSP generated by the final models selected from group 1 and group 2, respectively; $\alpha_0$ and $\alpha_1$ are the estimated coefficients.

[2] Critical value is $t_{0.025} = 1.960$.

### 5.1.2 UNITED STATES CONSTRUCTION INDUSTRY

The likelihood ratios from the models estimated for the United States construction industry are reported in Tables 4 and 5. Analogous to the results found for the Canadian industry, the partial adjustment model with technical bias appears to be the most appropriate model for representing the U.S. construction industry out of the four system of equation models (refer to Table 4).

In contrast to the findings for Canada, however, the likelihood ratios for the models in group 2 suggest that the logistic model with Hicks neutral technical change is the most superior in terms of goodness of fit.

Comparing the two models using the C-test, it was found that the partial adjustment model with biased technical change could not be rejected at the 95% confidence level (Table 3).

**Table 4: Specification Test Results From the Models In Group 1, United States Construction Industry.**

| Model Number[1] | Log of Likelihood Function | Hypothesis[2]/ Likelihood Ratio | Number of Restrictions | Critical $\chi^2_m$ (95%) | Test Outcome |
|---|---|---|---|---|---|
| 1 | 143.6010 | – | none | – | – |
| 2 | 129.4812 | (a) 28.24 | 6 | 12.59 | reject $H_o$ |
| 3 | 65.2684 | (b) 156.67 | 36 | 50.96 | reject $H_o$ |
| 4 | 10.9957 | (c) 265.21 | 42 | 58.11 | reject $H_o$ |

[1] Model 1 is the dynamic partial adjustment model with technical bias
Model 2 is the dynamic partial adjustment model without technical bias
Model 3 is the static, long-run model with technical bias
Model 4 is the static, long-run model without technical bias

[2] $H_o$ in (a) is that Model 2 is not statistically different from Model 1.
$H_o$ in (b) is that Model 3 is not statistically different from Model 1.
$H_o$ in (c) is that Model 4 is not statistically different from Model 1.

**Table 5: Specification Test Results From The Models In Group 2, United States Construction Industry.[1]**

| Model Number[2] | Log of Likelihood Function | Hypothesis[3]/ Likelihood Ratio | Number of Restrictions | Critical $\chi^2_m$ (95%) | Test Outcome |
|---|---|---|---|---|---|
| 1 | -49.5516 | – | none | – | – |
| 2 | -50.2491 | (a) 1.38 | 1 | 3.84 | do not reject $H_o$ |
| 3 | -52.9646 | (b) 6.83 | 2 | 5.99 | reject $H_o$ |
| 4 | -70.1171 | (c) 41.13 | 3 | 7.81 | reject $H_o$ |

[1] It should be remembered that these tests were performed on the NSP input/output demand equations only.

[2] Model 1 is the dynamic logistic model with technical bias
Model 2 is the dynamic logistic model without technical bias
Model 3 is the static, long-run model with technical bias
Model 4 is the static, long-run model without technical bias

[3] $H_o$ in (a) is that Model 2 is not statistically different from Model 1.
$H_o$ in (b) is that Model 3 is not statistically different from Model 1.
$H_o$ in (c) is that Model 4 is not statistically different from Model 1.

### 5.1.3 CONCLUSIONS

Examination of the "nested" and "non-nested" test results show that, out of all the models proposed and estimated in this study, the production technology and cost minimizing behavior of both the Canadian and U.S. construction industry is "best" represented by the dynamic, partial-adjustment model that includes disembodied biased technical change as an explanatory variable. These results lead us to conclude that the more restrictive models of forest products demand, especially the static, long-run models, employed by researchers in the past, are inappropriate for modeling the production technology and economic behavior of these industries. It is, however, premature to attribute the adjustment process to the innovativeness of NSP since the cause of the incomplete adjustment is not embodied in these test results.

## 5.2 RESULTS FROM THE FINAL MODEL

In this section, a detailed description of the results generated from the final models chosen in the preceding section are given.

### 5.2.1 GENERAL RESULTS

The estimated coefficients from each of the derived demand equations for the Canadian industry and their standard errors are given in Tables 6a, 6b, 6c, 6d, 6e, and 6f. As can be seen, only 8 of the 63 coefficients estimated are not significantly different from zero at the 95% confidence level (the critical asymptotic t-ratio is 1.96).

The results from the final model selected for the U.S. construction industry are given in Tables 7a, 7b, 7c, 7d, 7e, and 7f. Fourteen of the 63 coefficients are not significantly different from

**Table 6a: Estimated Coefficients From The NSP Input/Output Demand Equation, Final Model[1] - Canadian Construction Industry.**

| Coefficient | Estimated Value[2] | Standard Error | Coefficient | Estimated Value | Standard Error |
|---|---|---|---|---|---|
| $b_{NN}$ | -13.1104• | 4.5729 | $\phi_{NN}$ | 1.6994• | 0.1556 |
| $b_{NPT}$ | 23.8816• | 4.9496 | $\phi_{NPT}$ | -0.8812• | 0.1738 |
| $b_{NP}$ | -7.3897• | 2.0268 | $\phi_{NP}$ | 2.1129• | 0.7006 |
| $b_{NL}$ | -0.2267• | 0.1030 | $\phi_{NL}$ | -0.7186 | 0.5988 |
| $b_{NO}$ | 0.6057• | 0.1758 | $\phi_{NO}$ | 6.0267• | 0.8559 |
| $b_{NLK}$ | -0.0809• | 0.0411 | $\phi_{NLK}$ | -1.8769• | 0.3861 |
| $\gamma_N$ | 0.2169• | 0.0201 | | | |

[1] The final model is the partial adjustment with time.
[2] The coefficients marked with an asterik are significant at the 95% confidence level. Critical value is $t_{0.025} = 1.960$.

**Table 6b: Estimated Coefficients From The Particleboard Input/Output Demand Equation, Final Model - Canadian Construction Industry.**

| Coefficient | Estimated Value | Standard Error | Coefficient | Estimated Value | Standard Error |
|---|---|---|---|---|---|
| $b_{PTPT}$ | -38.7532• | 5.6615 | $\phi_{PTN}$ | 0.2795• | 0.1386 |
| $b_{PTP}$ | 18.3964• | 3.8697 | $\phi_{PTPT}$ | -0.2484• | 0.1056 |
| $b_{PTL}$ | 0.5385• | 0.1717 | $\phi_{PTP}$ | 0.5389• | 0.2352 |
| $b_{PTO}$ | -1.7002• | 0.2103 | $\phi_{PTL}$ | 3.8715• | 0.6308 |
| $b_{PTLK}$ | 1.2488• | 0.2129 | $\phi_{PTO}$ | 4.1225• | 0.7034 |
| $\gamma_{PT}$ | 0.1908• | 0.0322 | $\phi_{PTLK}$ | -1.7100• | 0.3693 |

[1] The final model is the partial adjustment with time.
[2] The coefficients marked with an asterik are significant at the 95% confidence level. Critical value is $t_{0.025} = 1.960$.

**Table 6c: Estimated Coefficients From The Plywood Input/Output Demand Equation, Final Model[1] - Canadian Construction Industry.**

| Coefficent | Estimated Value | Standard Error | Coefficient | Estimated Value | Standard Error |
|---|---|---|---|---|---|
| $b_{PP}$ | -7.8174* | 3.5615 | $\phi_{PN}$ | 0.1031* | 0.0373 |
| $b_{PL}$ | -0.4247* | 0.1030 | $\phi_{PPT}$ | -0.1603* | 0.0367 |
| $b_{PO}$ | 0.8604* | 0.1393 | $\phi_{PP}$ | 0.0038 | 0.0974 |
| $b_{PLK}$ | -0.3362* | 0.1128 | $\phi_{PL}$ | 0.9621* | 0.1645 |
| $\gamma_P$ | -0.0439* | 0.0192 | $\phi_{PO}$ | 1.0384* | 0.1811 |
| | | | $\phi_{PLK}$ | -0.2819* | 0.0846 |

[1] The final model is the partial adjustment with time.
[2] The coefficients marked with an asterik are significant at the 95% confidence level. Critical value is $t_{0.025} = 1.960$.

**Table 6d: Estimated Coefficients From The Lumber Input/Output Demand Equation, Final Model[1] - Canadian Construction Industry.**

| Coefficient | Estimated Value | Standard Error | Coefficient | Estimated Value | Standard Error |
|---|---|---|---|---|---|
| $b_{LL}$ | -0.0958 | 0.4394 | $\phi_{LPT}$ | -0.2529* | 0.0320 |
| $b_{LO}$ | 4.5905* | 0.3928 | $\phi_{LP}$ | -0.5577* | 0.1625 |
| $b_{LLK}$ | -0.6273* | 0.2727 | $\phi_{LL}$ | 1.9829* | 0.1417 |
| $\gamma_L$ | -0.0019 | 0.0114 | $\phi_{LO}$ | 1.2395* | 0.1671 |
| $\phi_{LN}$ | 0.0704* | 0.0282 | $\phi_{LLK}$ | -0.3802* | 0.0740 |

[1] The final model is the partial adjustment with time.
[2] The coefficients marked with an asterik are significant at the 95% confidence level. Critical value is $t_{0.025} = 1.960$.

Table 6e: Estimated Coefficients From The Other Building Materials Input/Output Demand Equation, Final Model[1] - Canadian Construction Industry.

| Coefficient | Estimated Value | Standard Error | Coefficient | Estimated Value | Standard Error |
|---|---|---|---|---|---|
| $b_{OO}$ | -15.4900• | 1.4807 | $\phi_{OPT}$ | -0.1427• | 0.0187 |
| $b_{OLK}$ | 13.7778• | 1.2731 | $\phi_{OP}$ | 0.4693• | 0.0978 |
| $\gamma_{O}$ | 0.1045• | 0.0165 | $\phi_{OL}$ | -0.0332 | 0.0347 |
| $\phi_{ON}$ | 0.0077 | 0.0088 | $\phi_{OO}$ | 0.7072• | 0.0871 |
| | | | $\phi_{OLK}$ | 0.1005• | 0.0380 |

[1]The final model is the partial adjustment with time.
[2]The coefficients marked with an asterik are significant at the confidence level. Critical value is $t_{0.025} = 1.960$.

Table 6f: Estimated Coefficients From The Labor/Capital Input/Output Demand Equation[1], Final Model - Canadian Construction Industry.

| Coefficient | Estimated Value | Standard Error | Coefficient | Estimated Value | Standard Error |
|---|---|---|---|---|---|
| $b_{LKLK}$ | -12.7644• | 1.3233 | $\phi_{LKP}$ | -0.3164• | 0.1136 |
| $\gamma_{LK}$ | -0.0650• | 0.0096 | $\phi_{LKL}$ | 0.2114• | 0.1021 |
| $\phi_{LKN}$ | -0.0241 | 0.0171 | $\phi_{LKO}$ | -0.0429 | 0.0514 |
| $\phi_{LKPT}$ | 0.0647• | 0.0166 | $\phi_{LKLK}$ | 1.0155• | 0.0313 |

[1]The final model is the partial adjustment with time.
[2]The coefficients marked with an asterik are significant at the 95% confidence level. Critical value is $t_{0.025} = 1.960$.

Table 7a: Estimated Coefficients From The NSP Input/Output Demand Equations, Final Model[1] - U.S. Construction Industry.

| Coefficient | Estimated Value | Standard Error | Coefficient | Estimated Value | Standard Error |
|---|---|---|---|---|---|
| $b_{NN}$ | 28.890* | 9.1078 | $\phi_{NN}$ | 0.4658* | 0.0864 |
| $b_{NPT}$ | 2.9123* | 0.8953 | $\phi_{NPT}$ | 0.7510 | 0.4331 |
| $b_{NP}$ | 4.4972* | 1.1406 | $\phi_{NP}$ | 4.4604* | 1.0940 |
| $b_{NL}$ | 18.8985* | 4.0014 | $\phi_{NL}$ | -1.5114* | 0.2173 |
| $b_{NO}$ | 0.1043 | 0.0548 | $\phi_{NO}$ | 3.4622 | 2.2555 |
| $b_{NLK}$ | 0.1278* | 0.0325 | $\phi_{NLK}$ | 2.0936* | 0.9162 |
| $\gamma_N$ | 3.1521* | 0.4980 | | | |

[1] The final model is the partial adjustment with time.
[2] The coefficients marked with an asterik are significant at the 95% confidence level. Critical value is $t_{0.025} = 1.960$.

Table 7b: Estimated Coefficients From The Particleboard Input/Output Demand Equation, Final Model[1] - U.S. Construction Industry.

| Coefficient | Estimated Value | Standard Error | Coefficient | Estimated Value | Standard Error |
|---|---|---|---|---|---|
| $b_{PTPT}$ | 3.1157* | 0.4262 | $\phi_{PTN}$ | 1.0359* | 0.2792 |
| $b_{PTP}$ | -0.7183* | 0.2443 | $\phi_{PTPT}$ | 1.0359* | 0.0928 |
| $b_{PTL}$ | -2.6102* | 0.8589 | $\phi_{PTP}$ | -1.7272* | 0.1601 |
| $b_{PTO}$ | -0.0649* | 0.0181 | $\phi_{PTL}$ | 0.1274* | 0.0598 |
| $b_{PTLK}$ | 0.0273* | 0.0113 | $\phi_{PTO}$ | 0.9427* | 0.1647 |
| $\gamma_{PT}$ | -0.1034* | 0.0133 | $\phi_{PTLK}$ | -0.3170* | 0.1267 |

[1] The final model is the partial adjustment with time.
[2] The coefficients marked with an asterik are significant at the 95% confidence level. Critical value is $t_{0.025} = 1.960$.

Table 7c: Estimated Coefficients From The Plywood Input/Output Demand Equation, Final Model - U.S. Construction Industry.

| Coefficent | Estimated Value | Standard Error | Coefficient | Estimated Value | Standard Error |
|---|---|---|---|---|---|
| $b_{PP}$ | 1.1341• | 0.5148 | $\phi_{PN}$ | 0.0369• | 0.0044 |
| $b_{PL}$ | -5.1297• | 1.1407 | $\phi_{PPT}$ | 0.1126• | 0.0405 |
| $b_{PO}$ | 0.2146• | 0.0710 | $\phi_{PP}$ | 0.2586• | 0.0566 |
| $b_{PLK}$ | -0.0103 | 0.0422 | $\phi_{PL}$ | -0.0772• | 0.0124 |
| $\gamma_P$ | -0.0252• | 0.0121 | $\phi_{PO}$ | 0.4875• | 0.1050 |
| | | | $\phi_{PLK}$ | 0.1552• | 0.0631 |

[1]The final model is the partial adjustment with time.
[2]The coefficients marked with an asterik are significant at the 95% confidence level. Critical value is $t_{0.025} = 1.960$.

Table 7d: Estimated Coefficients From The Lumber Input/Output Demand Equation, Final Model[1] - U.S. Construction Industry.

| Coefficient | Estimated Value | Standard Error | Coefficient | Estimated Value | Standard Error |
|---|---|---|---|---|---|
| $b_{LL}$ | -2.3341 | 4.7538 | $\phi_{LPT}$ | -0.5847• | 0.1488 |
| $b_{LO}$ | -0.2317• | 0.0787 | $\phi_{LP}$ | -5.5804• | 0.5756 |
| $b_{LLK}$ | 0.0240 | 0.0429 | $\phi_{LL}$ | 0.1985 | 0.1067 |
| $\gamma_L$ | 0.4679• | 0.1054 | $\phi_{LO}$ | 11.0189• | 0.8722 |
| $\phi_{LN}$ | 0.3107• | 0.0398 | $\phi_{LLK}$ | 0.6180 | 0.4295 |

[1]The final model is the partial adjustment with time.
[2]The coefficients marked with an asterik are significant at the 95% confidence level. Critical value is $t_{0.025} = 1.960$.

**Table 7e: Estimated Coefficients From The Other Building Materials Input/Output Demand Equation[1], Final Model - U.S. Construction Industry.**

| Coefficient | Estimated Value | Standard Error | Coefficient | Estimated Value | Standard Error |
|---|---|---|---|---|---|
| $b_{OO}$ | -1.9601• | 0.9272 | $\phi_{OP}$ | -0.3927• | 0.0735 |
| $b_{OLK}$ | 0.7254 | 0.4037 | $\phi_{OL}$ | -0.0267 | 0.0142 |
| $\gamma_{O}$ | -0.1024• | 0.0150 | $\phi_{OO}$ | 1.2495• | 0.1125 |
| $\phi_{ON}$ | 0.0462• | 0.0054 | $\phi_{OLK}$ | 0.0050 | 0.0633 |
| $\phi_{OPT}$ | 0.0555 | 0.0287 | | | |

[1]The final model is the partial adjustment with time.
[2]The coefficients marked with an asterik are significant at the 95% confidence level. Critical value is $t_{0.025} = 1.960$.

**Table 7f: Estimated Coefficients From The Labor/Capital Input/Output Demand Equation, Final Model[1] - U.S. Construction Industry.**

| Coefficient | Estimated Value | Standard Error | Coefficient | Estimated Value | Standard Error |
|---|---|---|---|---|---|
| $b_{LKLK}$ | -1.3269• | 0.2869 | $\phi_{LKP}$ | -0.3103• | 0.0510 |
| $\gamma_{LK}$ | -0.0471• | 0.0081 | $\phi_{LKL}$ | 0.0186• | 0.0081 |
| $\phi_{LKN}$ | 0.0165• | 0.0038 | $\phi_{LKO}$ | 0.0167 | 0.0679 |
| $\phi_{LKPT}$ | -0.0231 | 0.0205 | $\phi_{LKLK}$ | 1.0774• | 0.0409 |

[1]The final model is the partial adjustment with time.
[2]The coefficients marked with an asterik are significant at the 95% confidence level. Critical value is $t_{0.025} = 1.960$.

zero at the 95% confidence level.

The performance of the final models can also be assessed by inspecting how well the model tracks actual movements in demand. This is done by examining the correlation coefficients and the root-mean-square (RMS) percent error[39] between the observed values and predicted values for each of the input/output demand equations, and by visually inspecting these values at each observation point.

The correlation coefficients for each equation from the two final models are presented in Table 8. For Canada, the partial adjustment model with technical bias tracks the observed values more closely than the two static, instantaneous adjustment models. The final model outperforms the partial adjustment model without time for the N, PT, and L equations and only slightly outperformed for the O and LK equations.[40] The more restrictive partial adjustment model is far more superior for tracking the actual demand for plywood in Canada. Nonetheless, the most general model is maintained as the final model in this study. The root-mean-square (RMS) percent errors, which are shown

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[39]In this study the root-mean-square percent error test is defined as

$$\frac{1}{T}\left(\sum_{t=1}^{T}\left(\frac{a_t^s - a_t^a}{a_t^a}\right)^2\right)^{0.5}$$

where T is the number of observations, $a_t^s$ is the predicted value of $a_t$, and $a_t^a$ is the actual value of $a_t$. Clearly, the lower the RMS percent error, the better the simulation fit. Look to Pindyck et al (1981, p. 362) for a detailed overview of this test.

[40]Remember that N, PT, P, L, O and LK stands for NSP, particleboard, plywood, lumber, other building materials and labor/capital, respectively.

in brackets in Table 8, confirm the results revealed by the correlation coefficients.

**Table 8: Correlation Coefficients And Root-Mean-Square (RMS) Percent Error[1] Between The Observed And Predicted Values, Canadian And U.S. Construction Industries.**

| EQUATION / MODEL[2] | N | PT | P | L | O | LK |
|---|---|---|---|---|---|---|
| | $R^2$/(RMS percent error) | | | | | |
| (1a) | .8781 | .7353 | .4716 | .8249 | .8220 | .9315 |
| | (2.997) | (2.726) | (3.544) | (1.914) | (0.909) | (0.234) |
| (1b) | .8092 | .7282 | .7290 | .7932 | .8439 | .9422 |
| | (4.089) | (2.901) | (2.871) | (2.019) | (0.851) | (0.214) |
| (1c) | .6763 | .3528 | .0679 | .4544 | .6127 | .9111 |
| | (5.214) | (4.283) | (3.781) | (3.243) | (1.373) | (0.274) |
| (1d) | .0318 | .0006 | .0964 | .0471 | .3935 | .8847 |
| | (10.61) | (5.250) | (3.656) | (4.430) | (2.005) | (0.588) |
| (2a) | .9778 | .9690 | .9603 | .8083 | .9598 | .9800 |
| | (1.570) | (0.556) | (0.534) | (1.082) | (0.577) | (0.271) |
| (2b) | .9765 | .9610 | .9591 | .7835 | .9586 | .9731 |
| | (1.565) | (0.634) | (1.522) | (1.169) | (0.583) | (0.318) |
| (2c) | .9309 | .9294 | .7518 | .1816 | .8654 | .9681 |
| | (2.852) | (0.914) | (1.346) | (2.478) | (1.045) | (0.340) |
| (2d) | .4087 | .2796 | .5306 | .1161 | .4865 | .9693 |
| | (11.58) | (3.218) | (2.668) | (2.693) | (2.948) | (0.335) |

[1] RMS percent errors are shown in the brackets and are in percent.

[2] Model (1a) refers to the partial adjustment model with time for Canada
Model (1b) refers to the partial adjustment model without time for Canada.
Model (1c) refers to the static model with time for Canada.
Model (1d) refers to the static model without time for Canada.
Model (2a) refers to the partial adjustment model with time for U.S..
Model (2b) refers to the partial adjustment model without time for U.S
Model (2c) refers to the static model with time for U.S..
Model (2d) refers to the static model without time for U.S..

According to the correlation coefficients from the models for the U.S. construction industry, the partial adjustment model with technical bias outperforms all of the other models. Again, the RMS percent errors support this result.

A graph of the actual and predicted results is also very useful for examining the performance of the final models relative to the alternative models. A graphic representation provides a view of the behavior of the model at each data observation whereas the correlation coefficient only measures the overall performance of the model. Only the input/output demands for NSP are examined and discussed here, but a graphical representation of the other three wood products is provided in Appendix 2.

The graph in Figure 10 shows that the final model for the Canadian construction industry generally tracks the historical input/output demand for NSP very well. It captures the turning points extremely well but, in some instances, over- and under-estimates the magnitudes of the peaks and troughs. Nevertheless, the superiority of the partial adjustment model in terms of goodness of fit over the traditional static models is clearly apparent.

The input/output demand for NSP by the U.S. construction industry are illustrated in Figure 11. In general, like the results for the Canadian industry, the final model tracks the actual demands extremely well. Unlike the results for Canada, this model predicts the magnitudes of the peaks and troughs with a high degree of accuracy but tends to lag by one quarter period at many of the turning points. Again, nonetheless, as has been illustrated by Table 8 and Figure 11, this dynamic model outperforms the static specifications.

Although the final models are superior in terms of goodness of fit to the other models estimated in this study, it would appear from Figures 10 and 11 that the static model with time captures the average

**Figure 10: Predicted Versus Observed NSP Input/Output Demand, Canadian Construction Industry**

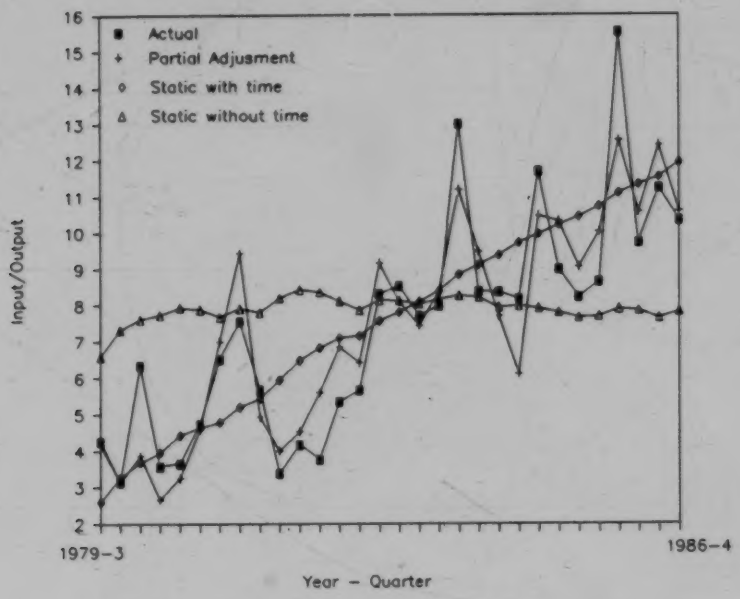
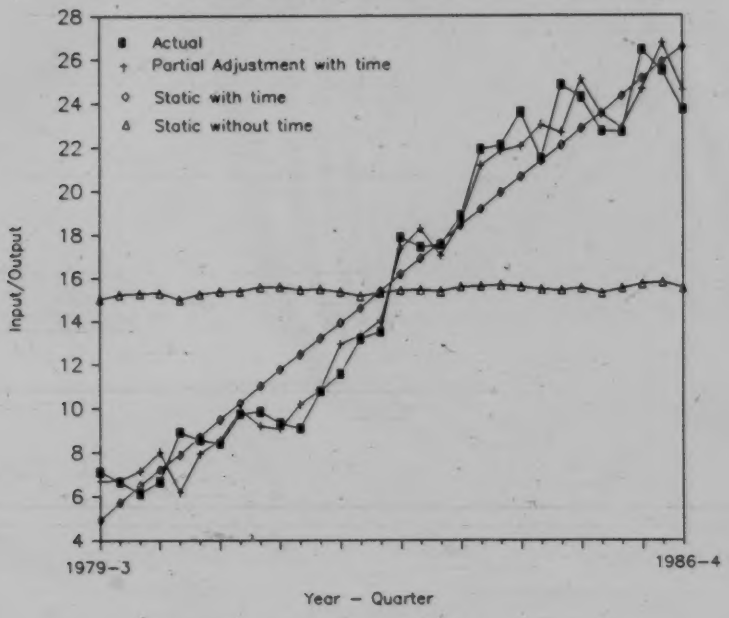



**Figure 11: Predicted Versus Observed NSP Input/Output Demand, United States Construction Industry**



trend of the observed data. This suggests that if the researcher is concerned only with modeling the long-run behavior of the industry than the static model with time can be employed. As an inspection of the long-run values generated from the final models and static models with time in Figures 12 and 13 shows, however, the long-run results from the static models are biased. For the Canadian industry, they are generally higher than those from the dynamic specification whereas the opposite is true for the results from the U.S. models. Thus, even if the sole interest of the research is in long-run demands, they cannot be derived from a static long-run model.

### 5.2.2 REGULARITY CONDITION TEST RESULTS

A summary of the regularity condition tests for the two final models is given in Table 9. These properties are evaluated on the long-run structure only since no optimizing behavior has been imposed in the short-run.[41]

As can be seen, monotonicity in prices is satisfied at the mean of the data for every equation except the "other building materials" equation for the U.S. industry.[42] Essentially then, the final model for the U.S. industry is not well-behaved with regard to this input thus the model becomes inapplicable for fully understanding the long-run

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[41]Even though no optimizing restriction were imposed on the short-run structure of the model, homogeneity of degree zero in prices and monotonicity in prices were satisfied in the short-run for both final models.

[42]It is worth noting that when Hicks neutral technical bias was maintained monotonicity was satisfied at each observation for each equation.

**Figure 12: Predicted Long-Run Results From The Final Model And The Static Model With Time, Canadian Construction Industry**

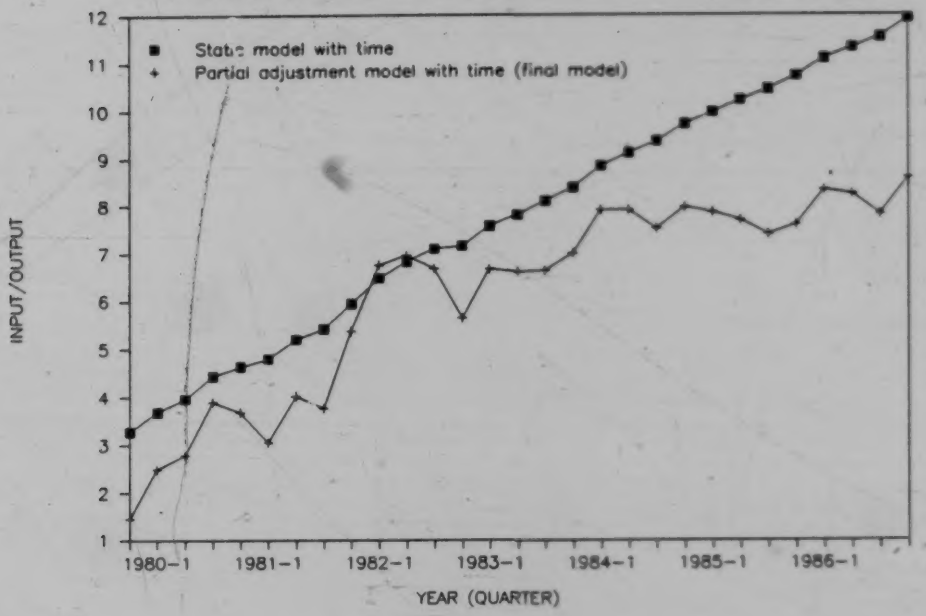


**Figure 13: Predicted Long-Run Results From The Final Model And The Static Model With Time, United States Construction Industry**

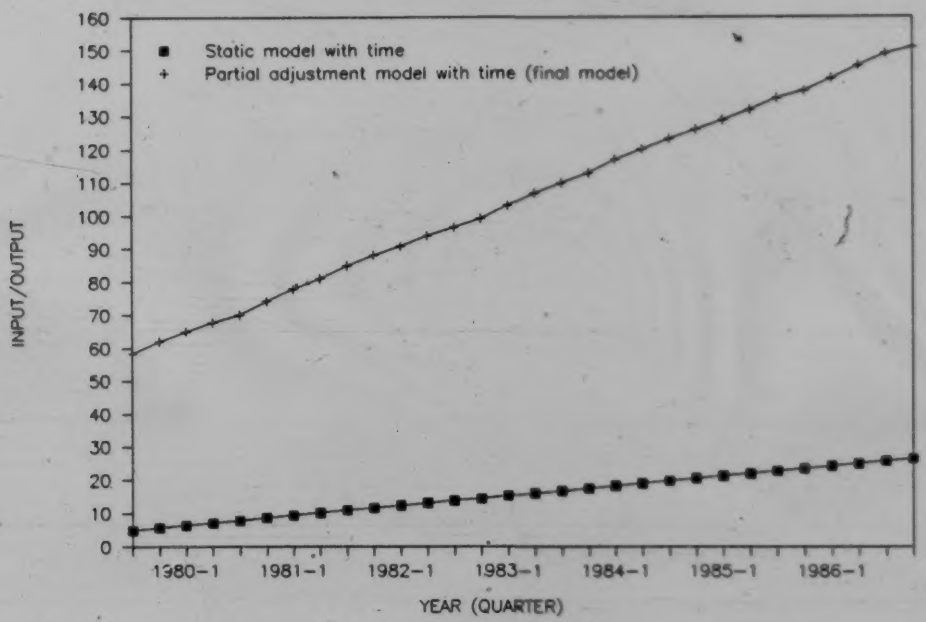

**Table 9: A Summary Of The Regularity Condition Tests, Final Models[1]**

| Country | | Canada | U.S. | Canada | U.S. |
|---|---|---|---|---|---|
| Property[2] | Equation | (at the mean of the data) | | (number of violations over the data set)[3] | |
| Quasi-concavity | | — | — | 27 | 30 |
| Monotonicity in prices | N | True | True | 1 | 0 |
| | PT | True | True | 0 | 1 |
| | P | True | True | 3 | 0 |
| | L | True | True | 0 | 0 |
| | O | True | False | 0 | 29 |
| | LK | True | True | 0 | 0 |
| Downward-sloping demands | N | True | True | 1 | 0 |
| | PT | True | True | 0 | 1 |
| | P | True | True | 3 | 5 |
| | L | True | True | 0 | 0 |
| | O | True | True | 0 | 29 |
| | LK | True | True | 0 | 0 |

[1] The final model for both countries is the partial adjustment model with time.

[2] These properties are evaluated for the long-run only.

[3] The data set is comprised of 30 observations.

structure of demand for this input. However, as is argued later on in this section, this violation does not preclude us from obtaining accurate measures on the demand for the other inputs.

The concavity results are also listed in Table 9. In the final model for the Canadian industry, this property was violated at 27 of the 30 observations and at all 30 observations in the final model for the U.S. industry.[43] This is an unfortunate result since, except for the three observation points in the Canadian model where concavity was satisfied, it suggests that cost minimization is not occurring. This raises our suspicions about the adequacy of the model results, and whether duality holds.[44]

On the other hand, some reassurance about the validity of the results can be regained by taking note of some earlier studies that, in some cases inadvertently, addressed these problems. For instance, when comparing the estimated coefficients from a unrestricted TL cost function with those from a cost function constrained to ensure global concavity, both Vertinsky et al. (1987) and Diewert & Wales (1985) found that the signs and magnitudes of the parameters did not differ by much. Moreover, in his analysis on the flexibility of the GL and TL utility function, Wales (1977) argued that "a violation of regularity

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[43]Concavity in the Canadian model was satisfied at observations 1982-1, 1982-2 and 1982-3.

[44]Lau, L.J. (1978) provides a method for imposing monotonicity and global concavity on the GL cost function. However, this involves constraining $b_{ij} > 0 \ \forall \ i, j$ which does not allow any of the inputs to be complements. According to *prior* expectations and previous studies this restriction would be erroneous hence concavity was checked rather than imposed in this study.

conditions in practice does not necessarily preclude the obtaining of good price and income elasticity estimates" (p. 191). He further noted that "even if quasi-concavity or monotonicity conditions are not satisfied, the use of flexible forms might be rationalized as a convenient method for summarizing market behavior ...".

It should also be pointed out that the checks used do not allow us to determine the statistical significance of these violations and hence it is possible that there exists a probability level in which concavity cannot be rejected.

To this end, even though concavity and monotonicity are violated at several observations, and since there are no easily employed statistical tests for measuring the significance of these violations, it can only be assumed that these findings do not necessarily imply biased and inaccurate estimates.

### 5.2.3 MISSPECIFICATION TEST RESULTS

The Durbin-Watson h-test is used to test for the presence of first order autocorrelation in each of the equations from the final models.[46] This statistic is used because the lagged dependent variable appears among the explanatory variables in each equation.

The computed h-tests are shown in Table 10 for Canada and Table 11 for the United States. The null hypothesis that first-order

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[46]Since quarterly data were used in estimation, it would have been informative to test for fourth order autocorrelation. However, no known test for this level of autocorrelation in dynamic models with lagged dependent variables exists thus it is not examined here.

**Table 10: Misspecification Test Results, Canadian Construction Industry.**

| Equation | Test: Durbin-Watson[1] h-test | Test: Runs Test[2] For Randomness |
|---|---|---|
| N | 0.721 | 13,16,16 |
| PT | -0.195 | 19,16,16 |
| P | -0.226 | 15,18,14 |
| L | 1.935 | 18,16,16 |
| O | -0.786 | 19,16,16 |
| LK | -0.587 | 19,14,18 |

[1] Critical t-value at the 95% significance level is 1.96.

[2] Refer to Gujarati (1978, pp. 246, 440-441) for a description of the Runs Test and the critical values.

**Table 11: Misspecification Test Results, United States Construction Industry.**

| Equation | Test: Durbin-Watson[1] h-test | Test: Runs Test[2] For Randomness |
|---|---|---|
| N | -1.749 | 15,13,18 |
| PT | -0.494 | 17,20,11 |
| P | 0.710 | 16,15,16 |
| L | -2.703 | 21,12,19 |
| O | 1.461 | 13,18,13 |
| LK | -0.296 | 17,15,16 |

[1] Critical t-value at the 95% significance level is 1.96.

[2] Refer to Gujarati (1978, pp. 246, 440-441) for a description of the Runs Test and the critical values.

autocorrelation does not exist[47] is only rejected in favor of negative first-order autocorrelation in the lumber input/output demand equation from the U.S. model.[48] In general, therefore, both models are not plagued with autocorrelation.

The results from the Runs test are also reported in Tables 10 & 11. Examination of these results reveal that randomness of the disturbance terms in all equations from the final models cannot be rejected at the 99% level of significance.

### 5.2.4 ELASTICITIES

#### 5.2.4.1 Own-Price Elasticities

The long-run own-price elasticities generated from the final model for the Canadian industry are given in Table 12. The long-run own-price elasticities are generally of the right sign with the exception of $\varepsilon_N$ in 1979-3 and $\varepsilon_P$ in 1979-3, 1986-3 and 1986-4. These positive elasticities are due to the violation of monotonicity (refer to section 5.2.3).

Except for lumber, input demand by the Canadian industry is relatively elastic. That is, input demand is very responsive to changes in own-price. However, the own-price elasticities for NSP and

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[47]First-order autocorrelation in the disturbance term can be expressed as:

$$u_{it} = \xi u_{it-1} + e_{it}$$

Hence, the null hypothesis ($H_o$) is that $\xi = 0$. Acceptance of $H_o$ would imply that first-order autocorrelation does not exist.

[48]Nonautocorrelation is also rejected for the U.S. lumber equation at the 99% significance level but not at the 99.8% level.

Table 12: Own-Price Elasticities Generated From The Final Model, Canadian Construction Industry, 3rd Quarter 1979 to 4th Quarter 1986.[1]

| YEAR/ QUARTER | INPUT DEMAND ELASTICITIES | | | | | |
|---|---|---|---|---|---|---|
| | N | PT | P | L | Q | LK |
| 1979-3 | 4.7588 | -1.8124 | –[2] | -0.6959 | -1.7205 | -1.2043 |
| 1979-4 | -4.8857 | -2.5845 | -5.2713 | -0.5513 | -2.4536 | -1.1725 |
| 1980-1 | -2.9910 | -2.9229 | -3.7700 | -0.5412 | -3.0164 | -1.1675 |
| 1980-2 | -2.6961 | -2.8091 | -4.4202 | -0.5479 | -2.8768 | -1.1650 |
| 1980-3 | -2.0414 | -3.3352 | -3.0092 | -0.5367 | -3.5814 | -1.1543 |
| 1980-4 | -2.1025 | -2.9086 | -3.9435 | -0.5436 | -2.9577 | -1.1863 |
| 1981-1 | -2.3971 | -2.4393 | -7.4257 | -0.5565 | -2.4720 | -1.2306 |
| 1981-2 | -1.9148 | -2.6833 | -4.9132 | -0.5463 | -2.6457 | -1.2473 |
| 1981-3 | -1.9820 | -2.4228 | -7.5507 | -0.5559 | -2.3960 | -1.2723 |
| 1981-4 | -1.5168 | -2.9933 | -3.6574 | -0.5343 | -3.3055 | -1.2567 |
| 1982-1 | -1.2933 | -3.8568 | -2.4623 | -0.5247 | -5.6873 | -1.2341 |
| 1982-2 | -1.2545 | -3.8553 | -2.3538 | -0.5240 | -5.8981 | -1.2369 |
| 1982-3 | -1.2707 | -3.4792 | -2.4299 | -0.5249 | -4.9309 | -1.2474 |
| 1982-4 | -1.3921 | -2.5723 | -4.2811 | -0.5328 | -3.1388 | -1.2704 |
| 1983-1 | -1.2395 | -2.8455 | -3.4122 | -0.5316 | -3.4514 | -1.2477 |
| 1983-2 | -1.2277 | -2.6113 | -4.2719 | -0.5380 | -2.8976 | -1.2444 |
| 1983-3 | -1.2092 | -2.5007 | -4.5950 | -0.5387 | -2.7316 | -1.2585 |
| 1983-4 | -1.1578 | -2.4445 | -5.2352 | -0.5402 | -2.6973 | -1.2609 |
| 1984-1 | -1.0687 | -2.7327 | -3.4845 | -0.5327 | -3.2343 | -1.2562 |
| 1984-2 | -1.0553 | -2.5721 | -3.9239 | -0.5355 | -2.9199 | -1.2576 |
| 1984-3 | -1.0687 | -2.3610 | -4.5373 | -0.5354 | -2.7902 | -1.2701 |
| 1984-4 | -1.0232 | -2.4089 | -4.0392 | -0.5317 | -3.2278 | -1.2533 |
| 1985-1 | -1.0166 | -2.2446 | -5.0966 | -0.5342 | -2.9737 | -1.2476 |
| 1985-2 | -1.0130 | -2.1024 | -6.7159 | -0.5381 | -2.6538 | -1.2445 |
| 1985-3 | -1.0200 | -1.9340 | -14.1553 | -0.5439 | -2.3035 | -1.2623 |
| 1985-4 | -0.9916 | -1.8872 | -23.7882 | -0.5451 | -2.2740 | -1.2622 |
| 1986-1 | -0.9354 | -1.9525 | -12.9251 | -0.5433 | -2.3826 | -1.2506 |
| 1986-2 | -0.9268 | -1.8463 | -65.8544 | -0.5541 | -2.1209 | -1.2298 |
| 1986-3 | -0.9370 | -1.7036 | – | -0.5667 | -1.9064 | -1.2378 |
| 1986-4 | -0.8844 | -1.7739 | – | -0.5547 | -2.0837 | -1.2319 |
| MEAN | -1.2761 | -2.3775 | -5.3184 | -0.5400 | -2.6980 | -1.2345 |

[1] The final model is the partial adjustment model with time.

[2] "–" indicates that monotonicity was rejected at these observations.

labor/capital are close to unity, and the price responsiveness of NSP and particleboard demand has been steadily declining over the study period.

In relation to the elasticities yielded by the competing models estimated in this study and by other authors, the elasticities from the final model are considerably higher (refer to Table 13); there is even a substantial difference between the elasticity values generated from the two partial adjustment specifications. These findings further emphasize the importance of including a dynamic adjustment mechanism as well as a time trend when modeling the production structure and economic behavior of the Canadian construction industry.

The long-run own-price elasticities from the final model for the U.S. construction industry are given in Table 14. At the mean of the data, they are of the right sign and are inelastic for the wood-inputs. These results are comparable to those yielded by the other models estimated in this study and to those found by Sharma (1986) and Spelter (1984, 1985) (refer to Table 15). Moreover, unlike the results found for the Canadian industry, derived demand elasticities from the two partial adjustment models are not substantially different.

#### 5.2.4.2. Cross-Price Elasticities

The long-run cross-price elasticities given in Tables 16 and 17 indicate a substitution relationship between NSP - particleboard, NSP - other building materials, particleboard - labor/capital, plywood - other building materials, and other building materials - labor/capital in both industries (Canada & U.S.). Particleboard - other building materials, plywood - lumber and plywood - labor/capital, on the other

**Table 13: A Comparison Of Estimated Price Elasticities For Wood Products Consumed In Canada.**

| Input | Study[1] | Elasticities[2] NSP | PARTICLEBOARD | PLYWOOD | LUMBER |
|---|---|---|---|---|---|
| NSP | (1a) | -1.28 | 2.03 | -0.75 | -0.00 |
| | (1b) | -0.72 | 0.66 | 0.06 | 0.00 |
| | (1c) | -0.11 | 0.26 | -0.16 | -0.00 |
| | (1d) | -0.38 | 0.42 | -0.04 | -0.00 |
| | (1e) | -1.36 | -3.17 | 1.76 | 0.77 |
| | (1f) | -1.59 | -3.41 | 1.71 | 0.64 |
| | (3) | -0.50 | – | 1.30 | – |
| PARTICLE-BOARD | (1a) | 1.21 | -2.38 | 1.17 | 0.00 |
| | (1b) | 0.64 | -0.42 | -0.23 | -0.00 |
| | (1c) | 0.22 | -0.26 | 0.04 | -0.00 |
| | (1d) | 0.36 | -0.25 | -0.11 | -0.00 |
| | (2) | – | -0.26 | 0.02 | 0.06 |
| PLYWOOD | (1a) | -3.35 | 8.66 | -5.32 | -0.02 |
| | (1b) | 0.24 | -1.01 | 0.77 | -0.00 |
| | (1c) | -0.45 | 0.12 | 0.32 | 0.00 |
| | (1d) | -0.11 | -0.37 | 0.48 | 0.00 |
| | (2) | – | 0.02 | 0.20 | 0.00 |
| LUMBER | (1a) | -0.86 | 2.12 | -2.01 | -0.54 |
| | (1b) | -0.61 | -0.46 | -0.08 | -0.24 |
| | (1c) | -0.45 | -0.69 | 0.22 | -0.15 |
| | (1d) | -0.24 | -0.44 | 0.02 | -0.16 |
| | (2) | – | 0.07 | 0.00 | -0.23 |

[1] (1a) refer to the partial adjustment model with time from this study.
(1b) refers to partial adjustment model without time from this study.
(1c) refers to static model with time from this study.
(1d) refers to static model without time from this study.
(1e) refers to logistic model with time from this study.
(1f) refers to logistic model without time from this study.
(2) refers to Sharma (1986) static estimates with TL.
(3) refers to Singh et al (1988) study of NSP.

[2] All estimates, except for study (3), are calculated at sample means. Estimates from (3) are for March 1985.

Table 14: Own-Price Elasticities Generated From The Final Model, U.S. Construction Industry, 3rd Quarter 1979 to 4th Quarter 1986.[1]

| YEAR/ QUARTER | INPUT DEMAND ELASTICITIES | | | | | |
|---|---|---|---|---|---|---|
| | N | PT | P | L | O | LK |
| 1979-3 | -0.1721 | -0.0721 | -0.0953 | -0.5295 | -7.4594 | -0.8458 |
| 1979-4 | -0.1661 | -0.0570 | -0.0702 | -0.5149 | -17.8883[2] | -0.9281 |
| 1980-1 | -0.1572 | -0.0646 | -0.0954 | -0.4998 | - | -0.9725 |
| 1980-2 | -0.1481 | -0.0759 | -0.1259 | -0.4861 | - | -1.0115 |
| 1980-3 | -0.1362 | -0.1077 | -0.1892 | -0.4752 | - | -1.0160 |
| 1980-4 | -0.1357 | -0.0807 | -0.1315 | -0.4607 | - | -1.1551 |
| 1981-1 | -0.1325 | -0.0689 | -0.1022 | -0.4472 | - | -1.3559 |
| 1981-2 | -0.1274 | -0.0715 | -0.1039 | -0.4357 | - | -1.4564 |
| 1981-3 | -0.1257 | -0.0519 | -0.0441 | -0.4213 | - | -1.7909 |
| 1981-4 | -0.1218 | -0.0494 | -0.0263 | -0.4097 | - | -1.7715 |
| 1982-1 | -0.1156 | -0.0691 | -0.0828 | -0.4024 | - | -1.9874 |
| 1982-2 | -0.1114 | -0.0768 | -0.0938 | -0.3932 | - | -2.2728 |
| 1982-3 | -0.1058 | -0.0988 | -0.1332 | -0.3875 | - | -2.2200 |
| 1982-4 | -0.1004 | -0.1253 | -0.1707 | -0.3828 | - | -1.9506 |
| 1983-1 | -0.1005 | -0.0977 | -0.1029 | -0.3691 | - | -2.1425 |
| 1983-2 | -0.0993 | -0.0794 | -0.0508 | -0.3577 | - | -2.2856 |
| 1983-3 | -0.0966 | -0.0827 | -0.0548 | -0.3495 | - | -2.5348 |
| 1983-4 | -0.0931 | -0.0981 | -0.0880 | -0.3437 | - | -3.1873 |
| 1984-1 | -0.0936 | -0.0472 | 0.0368 | -0.3295 | - | -3.7835 |
| 1984-2 | -0.0913 | -0.0510 | 0.0277 | -0.3221 | - | -5.9181 |
| 1984-3 | -0.0889 | -0.0712 | 0.0123 | -0.3153 | - | -8.6266 |
| 1984-4 | -0.0856 | -0.1092 | -0.0439 | -0.3120 | - | -7.3357 |
| 1985-1 | -0.0824 | -0.1471 | -0.0886 | -0.3092 | - | -6.3077 |
| 1985-2 | -0.0801 | -0.1806 | -0.1067 | -0.3045 | - | -7.1801 |
| 1985-3 | -0.0793 | -0.1783 | -0.0524 | -0.2956 | - | -7.1373 |
| 1985-4 | -0.0748 | -0.3064 | -0.1874 | -0.2985 | - | -8.4887 |
| 1986-1 | -0.0750 | -0.3350 | -0.1225 | -0.2873 | - | -12.5233 |
| 1986-2 | -0.0752 | -0.4588 | 0.0157 | -0.2763 | - | -11.5192 |
| 1986-3 | -0.0749 | -[3] | 0.2711 | -0.2678 | - | -7.6074 |
| 1986-4 | -0.0695 | -1.3900 | -0.1816 | -0.2753 | - | -14.0685 |
| MEAN | -0.1046 | -0.0918 | -0.0950 | -0.3793 | - | -2.0270 |

[1] The final model is the partial adjustment model with time.
[2] "-" indicates that monotonicity was rejected at this observation.

**Table 15: A Comparison Of Estimated Price Elasticities For Wood Products Consumed In The United States.**

| Input | Study[1] | Elasticities[2] NSP | PARTICLEBOARD | PLYWOOD | LUMBER |
|---|---|---|---|---|---|
| NSP | (1a) | -0.11 | 0.01 | 0.02 | 0.07 |
| | (1b) | -0.19 | 0.02 | 0.04 | 0.13 |
| | (1c) | -0.05 | 0.01 | 0.02 | 0.02 |
| | (1d) | -0.17 | 0.04 | 0.06 | 0.08 |
| | (1e) | -1.03 | -0.16 | 0.13 | 0.79 |
| | (1f) | -1.18 | -0.25 | 0.64 | 0.78 |
| | (5) | -0.56 | – | – | – |
| PARTICLE-BOARD | (1a) | 1.23 | -0.09 | -0.32 | -0.82 |
| | (1b) | 0.88 | -0.18 | -0.23 | -0.48 |
| | (1c) | 0.06 | -0.08 | 0.04 | -0.02 |
| | (1d) | 0.28 | -0.13 | -0.04 | -0.12 |
| | (2) | – | -0.13 | 0.23 | 0.01 |
| PLYWOOD | (1a) | 2.56 | -0.31 | -0.10 | -2.17 |
| | (1b) | 1.71 | -0.24 | 0.30 | -1.78 |
| | (1c) | 0.18 | 0.04 | -0.09 | -0.14 |
| | (1d) | 0.54 | -0.04 | -0.39 | -0.12 |
| | (2) | – | 0.03 | -0.16 | 0.15 |
| | (3) | – | – | -0.95 | 0.09 |
| | (5) | – | – | -0.10 | – |
| LUMBER | (1a) | 0.62 | -0.06 | -0.18 | -0.38 |
| | (1b) | 1.48 | -0.13 | -0.45 | -0.90 |
| | (1c) | 0.09 | -0.01 | -0.06 | -0.02 |
| | (1d) | 0.32 | -0.06 | -0.05 | -0.21 |
| | (2) | – | -0.01 | 0.12 | -0.38 |
| | (3) | – | – | 0.05 | -0.91 |
| | (4) | – | – | 0.004 | -0.11 |

[1] (1a) refers to partial adjustment model with time from this study.
(1b) refers to partial adjustment model without time from this study.
(1c) refers to static model with time from this study.
(1d) refers to static model without time from this study.
(1e) refers to logistic model with time from this study.
(1f) refers to logistic model without time from this study.
(2) refers to Sharma (1986) static estimates with TL.
(3) refers to Buongiorno (1988)
(4) refers to Spelter (1985).
(5) refers to Spelter (1984) estimates for plywood and structural particleboard.

[2] All estimates, except for study (4) & (5), are calculated at sample means. Estimates from (4) & (5) are for 1980 & 1981, respectively.

Table 16: Selected Cross-Price Elasticities And Elasticities Of Substitution ($\sigma_{ij}$) From The Final Model, Canadian Construction Industry.[1]

| | Cross-Price Elasticities | | | | $\sigma_{ij}$ |
|---|---|---|---|---|---|
| | 1979-4 | 1983-4 | 1986-4 | MEAN | MEAN |
| N-PT | 7.68 | 1.85 | 1.43 | 2.03 | 3.54 |
| PT-N | 1.37 | 1.21 | 0.89 | 1.21 | |
| N-P | -2.88 | -0.70 | -0.55 | -0.75 | -9.75 |
| P-N | -3.93 | -3.07 | —[2] | -3.35 | |
| N-L | -0.01 | -0.00 | -0.00 | -0.00 | -2.50 |
| L-N | -1.18 | -0.82 | -1.03 | -0.86 | |
| N-O | 0.02 | 0.00 | 0.00 | 0.00 | 3.33 |
| O-N | 0.99 | 1.10 | 0.92 | 1.14 | |
| N-LK | -0.00 | -0.00 | -0.00 | -0.00 | -0.15 |
| LK-N | -0.06 | -0.05 | -0.05 | -0.05 | |
| PT-P | 1.21 | 1.23 | 0.88 | 1.17 | 15.05 |
| P-PT | 9.23 | 8.33 | — | 8.66 | |
| PT-L | 0.00 | 0.00 | 0.00 | 0.00 | 3.70 |
| L-PT | 2.65 | 2.13 | 2.53 | 2.12 | |
| PT-O | -0.01 | -0.01 | -0.01 | -0.01 | -5.79 |
| O-PT | -2.63 | -3.35 | -2.68 | -3.33 | |
| PT-LK | 0.01 | 0.01 | 0.00 | 0.01 | 1.46 |
| LK-PT | 0.80 | 0.86 | 0.84 | 0.84 | |
| P-L | -0.02 | -0.02 | — | -0.02 | -26.01 |
| L-P | -2.53 | -2.05 | -2.48 | -2.01 | |
| P-O | 0.04 | 0.03 | — | 0.03 | 26.12 |
| O-P | 1.61 | 2.07 | 1.68 | 2.02 | |
| P-LK | -0.01 | -0.01 | — | -0.01 | -3.50 |
| LK-P | -0.26 | -0.28 | -0.28 | -0.27 | |
| L-O | 1.87 | 1.48 | 1.75 | 1.48 | 1170 |
| O-L | 0.74 | 0.71 | 0.55 | 0.73 | |
| L-LK | -0.25 | -0.20 | -0.22 | -0.20 | -54.92 |
| LK-L | -0.04 | -0.03 | -0.03 | -0.03 | |
| O-LK | 1.73 | 2.16 | 1.60 | 2.14 | 599 |
| LK-O | 0.73 | 0.77 | 0.76 | 0.75 | |

[1] The final model is the partial adjustment model with time.
[2] "—" indicates that monotonicity was rejected at these observations.

Table 17: Selected Cross-Price Elasticities And Elasticities Of Substitution ($\sigma_{ij}$) From The Final Model, United States Construction Industry.[1]

| | Cross-Price Elasticities | | | | $\sigma_{ij}$ |
|---|---|---|---|---|---|
| | 1979-4 | 1983-4 | 1986-4 | MEAN | MEAN |
| N-PT | 0.02 | 0.01 | 0.01 | 0.01 | 1.39 |
| PT-N | 0.72 | 1.68 | 15.78 | 1.23 | |
| N-P | 0.04 | 0.02 | 0.02 | 0.02 | 2.90 |
| P-N | 1.89 | 2.78 | 4.08 | 2.56 | |
| N-L | 0.12 | 0.06 | 0.05 | 0.07 | 0.70 |
| L-N | 0.81 | 0.55 | 0.47 | 0.62 | |
| N-O | 0.00 | 0.00 | 0.00 | 0.00 | – |
| O-N | –[2] | – | – | – | |
| N-LK | 0.00 | 0.00 | 0.00 | 0.00 | 1.41 |
| LK-N | 0.59 | 1.97 | 8.41 | 1.25 | |
| PT-P | -0.18 | -0.44 | -4.16 | -0.32 | -39.5 |
| P-PT | -0.20 | -0.30 | -0.55 | -0.31 | |
| PT-L | -0.48 | -1.14 | -10.21 | -0.82 | -8.19 |
| L-PT | -0.07 | -0.05 | -0.05 | -0.06 | |
| PT-O | -0.00 | -0.00 | -0.02 | -0.00 | – |
| O-PT | – | – | – | – | |
| PT-LK | 0.00 | 0.00 | 0.01 | 0.00 | 25.51 |
| LK-PT | 0.09 | 0.28 | 1.53 | 0.20 | |
| P-L | -1.62 | -2.41 | -3.36 | -2.17 | -21.67 |
| L-P | -0.22 | -0.16 | -0.14 | -0.18 | |
| P-O | 0.01 | 0.01 | 0.02 | 0.01 | – |
| O-P | – | – | – | – | |
| P-LK | -0.00 | -0.00 | -0.00 | -0.00 | -13.57 |
| LK-P | -0.05 | -0.17 | -0.73 | -0.11 | |
| L-O | -0.00 | -0.00 | -0.00 | -0.00 | – |
| O-L | – | – | – | – | |
| L-LK | 0.00 | 0.00 | 0.00 | 0.00 | 1.70 |
| LK-L | 0.08 | 0.28 | 1.14 | 0.17 | |
| O-LK | – | – | – | – | – |
| LK-O | 0.21 | 0.83 | 3.72 | 0.52 | |

[1] The final model is the partial adjustment model with time.
[2] "–" indicates that monotonicity was rejected at these observations.

hand, behave as complements in both industries. The "strength" of these relationships will be addressed in the next subsection.

Undoubtedly, one of the most interesting relationships that emerges from these cross-price elasticities is the complementary relationship between plywood and lumber. This result was anticipated *a priori* since, upon the advent of waterproof glues, plywood had captured the majority of the exterior sheathing market away from lumber by the 1970s and so plywood had "changed from being a substitute for lumber to being complementary to it" (Spelter, 1985, p. 686). However, the results from the static models estimated by Sharma (1986) and in this study do not support this expectation which suggests that the static models are dynamically misspecified and hence yield biased results.

For the Canadian industry, the final model implies that there exists a complementary relationship between NSP - plywood, NSP - lumber, NSP - labor/capital, and lumber - labor/capital while a substitution relationship exists between particleboard - plywood, particleboard - lumber and lumber - other building materials; the results from the final model model for the United States signify the opposite relationships (see Table 17).

The most unexpected relationship to materialize in this study was the complementary between NSP and plywood in Canada. Prior to this study it was felt that NSP was the principle substitute for plywood since the structural properties of these inputs are very similar. Perhaps the explanation for this relationship lies in the way the characteristics of the products that constitute the NSP input have changed over the study period. In the late 1970s, the non-veneered

structural panels group was by in large comprised of waferboard. At that time waferboard was not recognized as a structural product hence its use was limited to "do it yourself" applications. This may explain the complementary relationship between NSP and plywood.

As NSP producers developed a stronger product (i.e. OSB) and achieved approval to use their products in structural end-uses (i.e. roof sheathing), NSP products started to capture some of plywood's market share; nonetheless, a significant portion of NSP was still being consumed in non-structural end-uses. This latter argument is supported by the decline in the degree of complementary between NSP and plywood. Unfortunately, these speculations could not be tested in this study since disaggregated data were not readily available.[49]

**5.2.4.3 Elasticities of Substitution**

Elasticities of substitution measure the percentage change in the ratio of two cost-minimizing input levels as a result of an increase in the price ratio of the two inputs by one percent. Like the cross-price elasticities, this measure provides an indication of what the relationship between two inputs is, yet it is more valuable for measuring the extent or strength of the relationship and for comparing the two industries. The estimated results generated for Canada and the U.S. are presented in Tables 16 and 17, respectively. These results are reported at the mean of the data.

There are a number of interesting differences and similarities in

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[49]Although not shown here, it has been found that technical progress in the Canadian construction industry has been the dominant reason why NSP has captured a considerable portion of the structural panel market (refer to Figure 3).

the magnitudes of the elasticities of substitutions that stand out when comparing the results from the two construction industries - Canada and the U.S.. For instance, the complementary relationship between NSP and particleboard is stronger in the Canadian industry than it is in the U.S. construction industry. The converse is true for the substitution relationship between plywood and labor/capital. Another striking difference is the relationship between plywood and particleboard. In Canada, there is a strong substitution relationship between these inputs but a strong complementary relationship in the United States industry. This finding may be owing to differences in the properties of particleboard in the two countries or perhaps due to the level of acceptance of particleboard in the two industries. A relationship that is prevalent in both industries is the dominant complementary relationship between lumber and plywood.

To summarize, it is apparent from the above discussion of the various elasticities that the results from the chosen models for the two construction industries are generally consistent with our *a priori* expectations of the estimates.

### 5.2.5 TECHNICAL CHANGE

The results in Tables 6a to 6f show that all of the technical change parameters for the Canadian construction industry are significant at the 95% level except for the parameter on the lumber equation. Furthermore, the sizes of all the coefficients are relatively small thus the magnitude of technical change that has occurred in the industry is quite small.

The signs of the coefficients reveal that disembodied technical change in the Canadian construction industry has been NSP, particleboard and "other" building materials using but plywood and labor/capital saving. Since the coefficient on lumber is not significant, technical change with respect to lumber demand has been Hicks-neutral. In his study of the residential construction industry in Canada, Sharma (1986) found similar results to those found here.[50]

The findings discussed above provide some useful economic information about the Canadian construction industry. First of all, with regard to sheathing materials, the industry has adopted new technologies that capitalize on the relatively cheaper sheathing materials - NSP and particleboard - in a shift away from the slightly more expensive material - plywood. Secondly, over the study period, the industry has adopted technologies that have allowed it to save on the input that accounts for a large part (approximately 90%) of total construction costs - labor/capital.

All of the technical change coefficients in the U.S. model were significant at the 95% confidence level and, except for NSP, were small in magnitude.

The signs of the coefficients indicate that technical change in the U.S. construction industry has been NSP and lumber using but particleboard, plywood, other building materials and labor/capital saving. Sharma (1986) also found technical change in the U.S.

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[50]Since Sharma's (1986) study focused only on the residential construction industry, did not include NSP, and analyzed capital and labor as separate inputs, cautioned should be taken when comparing his results with the results found in this study.

residential industry to be plywood and other materials saving but, unlike this study, he found technical change to be lumber saving and particleboard using.

The U.S. construction industry has adopted new technology that increases its use of the NSP and decreases its use of particleboard and plywood. The large technical coefficient for NSP shows that the use of NSP using technology by the industry has increased dramatically over the study period.

Lastly, the U.S. construction industry has also adopted technologies that save on the high cost labor/capital input.

### 5.2.6 ADJUSTMENT COEFFICIENTS

It is obvious from the likelihood ratios that the construction industry in both Canada and the United States behaves in a dynamic fashion rather than a static one. This result is further supported by the significance of the individual adjustment coefficients. For the Canadian model, only six out of the thirty six adjustment coefficients were not statistically different from zero at the 95% significance level; from the U.S. model, nine of the thirty six were insignificant.

The cause of the adjustment process can be identified by examining the characteristics of the adjustment parameters; in particular the own-adjustment coefficients. This is especially important for determining if the adjustment mechanism has been due to the innovative nature of NSP products, which this study has postulated, or owing to some form of fixity in the other factor inputs, or some combination thereof. These issues are the focus of the remainder of this section.

Some interesting results that emerge from the two final models are with regard to NSP. The own-adjustment coefficient for NSP from the U.S. model was 0.4658.[51] This implies that, in the short-run, the industry only adjusts it consumption of NSP in response to a economic stimuli by 0.4658 of the desired, long-run level, *ceteris paribus*. This supports the hypothesis that the U.S. construction industry does not immediately adjust its use of NSP in response to an economic stimuli which suggests that there are certain risks involved when employing NSP.

For the Canadian industry, however, an opposite result arises. The own-adjustment coefficient on NSP is 1.69[52] which indicates that NSP can be instantaneously adjusted in the short-run and hence, despite its relatively infancy, NSP is not an innovative product in the Canadian construction industry. According to the magnitude of the own-adjustment parameters for the other inputs used by the Canadian industry, the cause of the adjustment process has accrued primarily from high adjustment costs in particleboard and plywood. It is possible that the construction industry has perceived these products as innovative because of product changes that have occurred in these goods over the study period. For example, a firm may have to study new building codes in order to use a plywood that is constructed with an improved bonding material.

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[51]The 95% confidence interval for the own-adjustment coefficient on U.S. NSP is 0.2965 to 0.6351.

[52]The 95% and 99.9% confidence interval for the own-adjustment coefficient on Canadian NSP is 1.3941 to 2.0044 and 1.1873 to 2.2115, respectively.

From these results, a question that comes to mind is why has the market penetration of NSP been much faster in the Canadian construction industry than it has in the U.S. industry? Differences between the two countries in terms of research & development in wood products, in access to well-tested technologies, in overall growth of the economy or industry, in supply of raw materials for production, in shortage of raw materials for producing competing products, or in the characteristics of the products themselves could be some of the factors leading to these findings.[53] However, since the intent of this research has been to account for the innovative behavior of NSP and not to measure the factors influencing the diffusion of NSP, this question can not be adequately addressed here and thus is left for future research.

Another result that is worth noting is the magnitude of the own-adjustment coefficients for the labor/capital inputs in both industries. They are not significantly different from one which implies that labor/capital is not quasi-fixed in the short-run. Considering that the construction industry does not use large pieces of physical capital and that labor can be hired virtually on demand, this outcome is not surprising.

A final point is that the only own-adjustment parameter that seems to have an nebulous economic meaning is the own-adjustment coefficient on particleboard in the Canadian model. It is of a negative value which, as noted in Chapter 4, is difficult to explain. In consequence, results employing this coefficient should be interpreted with care.

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[53]Bengston (1984) and Buongiorno & Oliveira (1977) measured the impact of some of these factors on the diffusion of particleboard.

# Chapter 6

## CONCLUSIONS

Since the introduction of non-veneered structural wood panels, and especially since 1979, the demand for NSP has been increasing rapidly in both Canada and the United States. It is not clear, however, if this growth in demand has been solely the consequence of lower prices for NSP relative to competing materials, or if it has also been a result of increasing market acceptance of these products.

Drawing from the theory of diffusion, the data for NSP and the existing wood products literature, it was hypothesized that, since NSP is a relatively new product, it is unlikely that all firms in the construction industry, who are the principal consumer of wood building materials, would immediately adopt these products irrespective of the price advantage and consume them at their economic optimum levels. The main reason being that certain risks and uncertainties exist when an innovation is adopted.

It was found that the traditional econometric models that have been used to measure the demand for wood products were inadequate for testing the hypothesis proposed here. The static neoclassical production approach was appropriate in that the demand for factor inputs (wood products) are explicitly derived from the production technology of the consuming firm. They were deemed inappropriate, however, since they did not allow for the existence of adjustment costs that arise when innovations are adopted. The models introduced by Spelter (1984, 1985) and Singh et al (1988) have attempted to account

for the existence of adjustment costs but are inadequate in that their models are not explicitly derived from the production technology and optimizing behavior of the consuming industry.

Given the shortcomings embodied in the previous approaches, two dynamic formulations - the partial adjustment and logistic model - that combine the neoclassical theory of the firm with the models used in diffusion research were developed. These two models would then be tested against the traditional static neoclassical model and against each other in order to determine if the Canadian and U.S. construction industries have been behaving in a dynamic manner due to the innovativeness of NSP, and to choose a model that best describes the actual economic behavior of these industries.

A Generalized Leontief (GL) cost function was adopted to represent the underlying economic behavior of both the Canadian and United States construction industries. It was assumed that the industry used non-veneered structural wood panels (NSP), particleboard (PT), plywood (P), lumber (L), other building materials (O) and labor/capital (LK) as inputs in its production process.

The data set was comprised of quarterly time-series data covering the period 1979-3 to 1986-4. It included prices and quantities of the six inputs and a measure of industry output. The parameters of the static models were estimated using Zellner's method for seemingly unrelated regressions while a non-linear procedure was used to estimate the parameters of the dynamic models.

The final model chosen for both the Canadian and U.S. construction industries was the partial adjustment model with Hicks-biased technical

change. The conclusions that were drawn from the selection of this model were that factor inputs are not adjusted instantaneously to long-run equilibrium levels, and technical change has not affected factor inputs equally in either industries. However, the individual adjustment coefficients had to be examined in order to determine if NSP could be considered an innovative product.

The own-adjustment coefficient for NSP indicated that in Canada NSP is not costly to adjust in the short-term and hence is not an innovative product. Nonetheless, examination of the cross-adjustment parameters indicated that the demand for NSP by the Canadian industry has not only been governed by relative factor prices and disembodied technical change but also by excess demand or supply in the other factor markets. For the U.S., NSP was found to be an innovative product. Thus, over the study period the demand for NSP has been governed by relative factor prices, innovativeness of NSP, technical change, and excess demand or supply in the other factor markets.

There were several other interesting results that emerged from this study. Disembodied technical change was NSP-using but plywood-saving in both industries. That is, these construction industries have adopted technologies that allow them to use more of the cheaper panel product - NSP - and less of the expensive panel - plywood. In general, the elasticity measures were as expected. However, the long-run complementary relationship between NSP and plywood in the Canadian industry was unexpected. Without further analysis, it is difficult to determine why this relationship exists but the answer may lie in the differences in building codes and in product characteristics

that make up the NSP input between the two countries. Finally, the complementary relationship found between lumber and plywood in both industries was opposite to the result generated by the traditional static models. Over time, plywood has gone from being a substitute to a complement to lumber. The dynamic models chosen in this study reveal this relationship while the static models do not which suggests that the latter are misspecified and do not provide a good description of the industry.

A number of caveats regarding this research should be raised in order to qualify the results found. The first concerns the fact that the own-adjustment parameters were not endogenously modeled. In Chapters 2 and 3 it was suggested that an innovation will become fully adopted by all potential users as time progresses. Hence, the own-adjustment parameter for an innovative product should approach 1 as the product matures. Unfortunately, the own-adjustment parameters are only an average of the historical adjustment process and cannot change over time. This should be kept in mind when using the results for short-run forecasting.

Another caveat regards the violation of concavity and monotonicity at several observations. These findings suggest that the model is not well-behaved at all observations which weakens our confidence about the accuracy of the results. Nonetheless, based on the arguments presented in Chapter 5, we can only assume that the model satisfies these properties at some probability level.

Finally, there are several caveats relating to the construction of the data but these are discussed in the data appendix.

Since this study is one of the first that attempts to integrate the neoclassical theory of production with the theory of diffusion, there are many avenues for further research. One of the most interesting avenues would be to disaggregate the data into regions so that spatial diffusion (diffusion from one region to another) could be analyzed. This could also involve trying to identify and measure the factors governing the diffusion of NSP within a region and across regions which would involve endogenizing the adjustment parameters.[54]

The second avenue would be to develop a model that is fully embodied by the neoclassical theory of the firm. The partial adjustment approach adopted here is ad hoc in that it was not explicitly derived from a short-run cost function. In consequence, no theoretical restrictions were imposed on the short-run component of the model, and the short-run elasticities were not consistent with the *Le Chatelier - Samuelson* principle. Despite these shortcomings, however, it has been argued that the approaches adopted here are improvements over the traditional static models and the models introduced by Spelter (1984, 1985) and Singh et al. (1988).

A final avenue would be to explicitly include inventories of factor inputs held by the construction industry in the model. The behavior of the construction industries to deplete and replenish inventories could be an important factor influencing the demand for inputs in the short-run. Inventory adjustment may explain some of the

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[54]Griliches (1958) focused on the spatial diffusion of hybrid corn in the United States whereas Buongiorno and Oliveira (1977) were concerned with trying to identify why the adoption and diffusion of particleboard varied between countries.

results obtained in which short-run responses were larger in magnitude than long-run adjustments thus contradicting the *Le Chatelier - Samuelson* principle. Inclusion of an inventory variable in a more complete model could correct this result. An inventory variable was not included in this work because of data inavailability, and would appear to be an area worth investigating.

To conclude, this research has introduced several alternative approaches to modeling the derived demand for innovative wood products. These approaches are superior to previous models in that they are well embodied by the theory of the firm and allow for the existence of adjustment costs. The results have provided many useful insights into the behavior of the two construction industries towards the relatively new forest product NSP, and into the relationships between NSP and the other inputs used by these industries. Although not shown here, the responsiveness of NSP demand toward price shocks and policy changes can be examined with the results generated from this study. Finally, this study and the results found provide a stepping stone for future research into the area of modeling the derived demand for innovative forest products.

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# Appendix 1

## DATA DESCRIPTION AND SOURCES

The data to be used in estimation of all the models proposed in this study includes: input prices of the seven factors of production; total physical quantities of each input used in the three construction sectors (residential, nonresidential, and repairs & alterations (R&A)); output of the three construction industries; and instrumental variable data.

The data set is comprised of quarterly data from the third quarter of 1979 to the fourth quarter in 1986, resulting in 30 observations per variable.[55] Wherever necessary, monthly data were converted to a quarterly time series, and standard units were converted to metric units. Furthermore, all input and output prices collected for the U.S. were converted to Canadian dollars using the noon spot rate reported by the *Bank of Canada Review*.

For both Canada and the United States, a detailed description of how the final data were constructed and data sources are given below. The final data used to estimate the models in this study are reported in Tables A1.1 and A1.2 for Canada and the United States, respectively.

### A1.1 CANADA

#### A1.1.1 NON-VENEERED STRUCTURAL WOOD PANELS (NSP)[56]

Quarterly data on total domestic consumption and unit prices of NSP were constructed from data reported in the monthly Statistics Canada publication *Particleboard, Waferboard and Hardboard* (catalogue 36-003). In this catalogue, total shipments, which includes exports, are reported in both cubic metres and thousands of dollars. This allowed monthly producer prices to be derived by dividing the value of shipments by the quantities of shipments.

Since Canada does not import NSP, total domestic consumption (cubic metres) was computed by subtracting total quantities of exports, which were also available from cat. 36-003, from total shipments.

Finally, in order to determine the amount of NSP consumed by the three aforementioned construction sectors, the percent of total domestic consumption of NSP used in these sectors for the 1979-1986 period was required. This information was available from industry

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[55] This particular time series was chosen because data for the NSP were only available for this period. Also, since some of the data were only available in a quarterly series, a quarterly time series was chosen. Finally, data were actual collected for the first two quarters of 1979 as well; however, since lagged variables were included in some of the models and the data for the first quarter in 1979 for NSP was erroneous, results are not estimated for these periods.

[56] For both Canada and the United States, separate data for waferboard and oriented strandboard are not available, hence they are modeled as a single homogeneous product.

## Table A1.1: Data Used In Estimation Of Proposed Models, Canadian Construction Industry.[1]

| YEAR - QUARTER | N[2] | | PT | | P | | L | | O | | LBK | | OUTPUT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | O[3] | P | Q | P | Q | P | Q | P | Q | P | Q | P | |
| 1979-1 | 62310.3 | 174.409 | 105993. | 127.164 | 304687. | 249.0340 | 0.2082950E+09 | 1.421343 | 0.2771510E+09 | 0.8150922 | 0.9023195E+10 | 0.7597990 | 0.9099852E+10 |
| -2 | 52104.3 | 173.561 | 110705. | 126.515 | 316050. | 231.5745 | 0.2382767E+09 | 1.392560 | 0.3735419E+09 | 0.8503156 | 0.1217657E+11 | 0.7677301 | 0.1197814E+11 |
| -3 | 62468.2 | 171.390 | 104276. | 116.384 | 254167. | 202.1621 | 0.2109717E+09 | 1.586301 | 0.4309555E+09 | 0.8403963 | 0.1500519E+11 | 0.7874566 | 0.1464803E+11 |
| -4 | 40821.4 | 146.878 | 106477. | 127.593 | 209600. | 182.6617 | 0.2041928E+09 | 1.402332 | 0.3575254E+09 | 0.8432581 | 0.1297854E+11 | 0.8254626 | 0.1295255E+11 |
| 1980-1 | 63380.8 | 134.170 | 105394. | 131.339 | 242698. | 198.9552 | 0.2139546E+09 | 1.234876 | 0.2674668E+09 | 0.8978826 | 0.9546924E+10 | 0.8823791 | 0.9992930E+10 |
| -2 | 43711.6 | 121.165 | 95868.9 | 146.530 | 241293. | 202.7127 | 0.2215845E+09 | 0.9461698 | 0.3259968E+09 | 0.9140517 | 0.1224294E+11 | 0.8755335 | 0.1220056E+11 |
| -3 | 52819.2 | 135.153 | 86957.7 | 151.124 | 249033. | 216.5209 | 0.2009605E+09 | 1.139667 | 0.3662259E+09 | 0.9044963 | 0.1427681E+11 | 0.9217410 | 0.1443983E+11 |
| -4 | 62098.6 | 162.108 | 97311.5 | 155.232 | 257204. | 224.9125 | 0.2135586E+09 | 1.050411 | 0.3109324E+09 | 0.9343585 | 0.1272762E+11 | 0.9621698 | 0.1309228E+11 |
| 1981-1 | 69257.6 | 153.495 | 106951. | 160.076 | 266092. | 251.4204 | 0.2728421E+09 | 1.000000 | 0.2371725E+09 | 1.000000 | 0.1003233E+11 | 1.000000 | 0.1063700E+11 |
| -2 | 103884. | 162.139 | 114976. | 163.227 | 309137. | 286.9318 | 0.3292790E+09 | 1.074860 | 0.3783103E+09 | 1.033599 | 0.1256230E+11 | 1.063877 | 0.1375950E+11 |
| -3 | 86857.0 | 164.004 | 94138.2 | 178.852 | 189678. | 296.6783 | 0.1974603E+09 | 1.051447 | 0.3942576E+09 | 1.040949 | 0.1361113E+11 | 1.140216 | 0.1528431E+11 |
| -4 | 45586.9 | 134.290 | 78885.7 | 167.953 | 207503. | 230.7692 | 0.2323047E+09 | 0.8639366 | 0.3125901E+09 | 1.068799 | 0.1233717E+11 | 1.135345 | 0.1342831E+11 |
| 1982-1 | 43867.2 | 133.800 | 67187.5 | 170.839 | 176205. | 222.7272 | 0.1971440E+09 | 0.8530470 | 0.2176538E+09 | 1.151561 | 0.9426909E+10 | 1.168526 | 0.1049115E+11 |
| -2 | 46165.0 | 128.320 | 69565.2 | 169.870 | 170549 | 202.9356 | 0.2303298E+09 | 0.8996532 | 0.2467804E+09 | 1.151025 | 0.1099857E+11 | 1.182007 | 0.1224109E+11 |
| -3 | 70887.1 | 152.968 | 63261.7 | 158.303 | 156189. | 208.6538 | 0.2115053E+09 | 0.9082565 | 0.2688871E+09 | 1.154120 | 0.1215323E+11 | 1.171797 | 0.1322098E+11 |
| -4 | 68852.9 | 150.742 | 76952.4 | 168.396 | 178951. | 224.5265 | 0.2102429E+09 | 0.9895528 | 0.2308998E+09 | 1.150179 | 0.1141910E+11 | 1.137556 | 0.1213518E+11 |
| 1983-1 | 78500.5 | 149.964 | 93752.9 | 168.960 | 204611. | 242.1401 | 0.2422451E+09 | 1.125357 | 0.2226744E+09 | 1.190103 | 0.8621599E+10 | 1.144245 | 0.9449385E+10 |
| -2 | 106174. | 149.852 | 102393. | 174.873 | 255385. | 252.3674 | 0.2858131E+09 | 1.253710 | 0.2993433E+09 | 1.202981 | 0.1159341E+11 | 1.127132 | 0.1245562E+11 |
| -3 | 109755. | 164.169 | 83133.1 | 178.462 | 218095 | 287.0629 | 0.2661965E+09 | 1.245087 | 0.3138896E+09 | 1.200996 | 0.1339983E+11 | 1.137486 | 0.1426005E+11 |
| -4 | 98039.7 | 143.954 | 90785.8 | 173.622 | 202739. | 233.1439 | 0.2686319E+09 | 1.043303 | 0.2277367E+09 | 1.197146 | 0.1159448E+11 | 1.141057 | 0.1228085E+11 |
| 1984-1 | 122668. | 147.041 | 98164.6 | 177.097 | 189957. | 251.5151 | 0.2674710E+09 | 1.151982 | 0.1914010E+09 | 1.218736 | 0.8675627E+10 | 1.171260 | 0.9434413E+10 |
| -2 | 102268. | 151.985 | 100074. | 185.555 | 188734. | 238.7770 | 0.2869445E+09 | 1.115029 | 0.3059436E+09 | 1.238939 | 0.1122711E+11 | 1.183103 | 0.1220544E+11 |
| -3 | 117588. | 154.193 | 90603.5 | 187.794 | 188531. | 225.8724 | 0.2737870E+09 | 0.9446469 | 0.3192672E+09 | 1.260707 | 0.1339154E+11 | 1.162087 | 0.1407042E+11 |
| -4 | 98825.8 | 170.928 | 110687. | 189.397 | 173564 | 236.5291 | 0.2868284E+09 | 1.000605 | 0.2407436E+09 | 1.299394 | 0.1169479E+11 | 1.159739 | 0.1209048E+11 |
| 1985-1 | 111156. | 173.187 | 120465. | 188.524 | 189558. | 235.8630 | 0.2874279E+09 | 1.058665 | 0.1941899E+09 | 1.275078 | 0.8966802E+10 | 1.187986 | 0.9501116E+10 |
| -2 | 117162. | 171.026 | 122917. | 182.480 | 228104. | 238.5272 | 0.3516837E+09 | 1.141499 | 0.3198169E+09 | 1.291304 | 0.1258638E+11 | 1.158053 | 0.1303272E+11 |
| -3 | 126501. | 188.377 | 125616. | 183.635 | 224412. | 266.0016 | 0.3228562E+09 | 1.172504 | 0.3491975E+09 | 1.313907 | 0.1516435E+11 | 1.147431 | 0.1539989E+11 |
| -4 | 117868. | 193.524 | 136041. | 193.311 | 185991. | 289.8959 | 0.3210185E+09 | 1.121640 | 0.2986772E+09 | 1.329073 | 0.1347512E+11 | 1.151822 | 0.1364501E+11 |
| 1986-1 | 170847. | 185.889 | 147104. | 195.862 | 238293. | 300.8024 | 0.3195538E+09 | 1.136939 | 0.2396918E+09 | 1.346034 | 0.1080212E+11 | 1.159569 | 0.1100767E+11 |
| -2 | 135699. | 196.840 | 141383. | 198.882 | 228896. | 312.0419 | 0.3790903E+09 | 1.370650 | 0.3492805E+09 | 1.365644 | 0.1429837E+11 | 1.121117 | 0.1394855E+11 |
| -3 | 175534. | 196.604 | 134016. | 204.217 | 205444. | 321.8661 | 0.3389190E+09 | 1.257957 | 0.3673997E+09 | 1.374057 | 0.1634365E+11 | 1.127889 | 0.1561071E+11 |
| -4 | 140264. | 204.227 | 161160. | 220.468 | 222097. | 354.5023 | 0.3010829E+09 | 1.302146 | 0.3047970E+09 | 1.378413 | 0.1420068E+11 | 1.149515 | 0.1356056E+11 |

[1] Source: Appendix 1

[2] Quantity & price units for N, PT and P are cubic metres and $/cubic metres, respectively. Data for L, O, LBK and OUTPUT are indexed

[3] O stands for quantity, P stands for unit price.

## Table A1.2: Data Used In Estimation Of Proposed Models, United States Construction Industry.[1]

| YEAR - QUARTER | N[2] | | PT | | P | | L | | O | | LBK | | OUTPUT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Q[3] | P | Q | P | Q | P | Q | P | Q | P | Q | P | |
| 1979-1 | 79641.13 | 251.6712 | 782252.8 | 89.82790 | 2831684 | 228.8152 | 14445182 | 121.9913 | 0.3127264E+10 | 0.8253791 | 0.4765277E+11 | 0.6820913 | 153953393 |
| -2 | 141584.2 | 224.3476 | 856584.6 | 85.50143 | 3840472 | 211.1361 | 15977705 | 122.3493 | 0.3915693E+10 | 0.8148875 | 0.6029864E+11 | 0.6832508 | 188891566 |
| -3 | 150433.2 | 245.1689 | 955693.5 | 79.08681 | 3902415 | 222.7611 | 16054183 | 139.0454 | 0.3980766E+10 | 0.8133366 | 0.6737549E+11 | 0.7019932 | 211277004 |
| -4 | 132735.2 | 215.0781 | 877822.2 | 83.64153 | 3344927 | 204.8995 | 13903449 | 120.9679 | 0.3617022E+10 | 0.8514915 | 0.5872572E+11 | 0.7780052 | 199473150 |
| 1980-1 | 97339.16 | 198.4943 | 715000.3 | 132.8935 | 2575063 | 192.5420 | 12173385 | 107.8816 | 0.2916602E+10 | 0.8661145 | 0.4387807E+11 | 0.8448009 | 158263476 |
| -2 | 115037.1 | 196.0716 | 677834.5 | 148.0927 | 2822835 | 185.1158 | 10830752 | 90.89494 | 0.3040153E+10 | 0.9636996 | 0.4833390E+11 | 0.8428734 | 172392914 |
| -3 | 159282.2 | 228.9269 | 761015.2 | 120.8849 | 3229890 | 214.7126 | 12401790 | 103.4170 | 0.3258209E+10 | 0.9392562 | 0.4979190E+11 | 0.8615244 | 178912070 |
| -4 | 159282.2 | 216.7440 | 768094.4 | 102.1284 | 3132551 | 225.2176 | 11986827 | 100.3333 | 0.3254873E+10 | 0.9170597 | 0.4766533E+11 | 0.9552535 | 185826274 |
| 1981-1 | 132735.2 | 188.4483 | 672525.1 | 108.8042 | 2557365 | 210.8643 | 11348914 | 101.1496 | 0.2895983E+10 | 1.000000 | 0.3756750E+11 | 1.000000 | 157983075 |
| -2 | 176980.3 | 182.2719 | 715000.3 | 116.4838 | 3088306 | 209.9418 | 11449669 | 108.1756 | 0.3381398E+10 | 0.9818412 | 0.4390109E+11 | 1.054501 | 181513018 |
| -3 | 185829.3 | 167.8422 | 755705.8 | 105.4394 | 2973269 | 198.0981 | 9717590. | 100.6354 | 0.3311228E+10 | 1.043047 | 0.4297279E+11 | 1.134649 | 188957258 |
| -4 | 159282.2 | 160.4590 | 667215.6 | 91.13203 | 2495422 | 185.4064 | 9433080. | 86.52084 | 0.2719787E+10 | 0.9623608 | 0.3972878E+11 | 1.125995 | 171157099 |
| 1982-1 | 123886.2 | 159.2573 | 555718.1 | 107.0173 | 2132612 | 181.7017 | 8893340. | 85.71811 | 0.2257001E+10 | 0.9720250 | 0.3052611E+11 | 1.170738 | 136449337 |
| -2 | 185829.3 | 168.3851 | 610582.0 | 122.3706 | 2725496 | 185.1969 | 12482869 | 90.18554 | 0.2874211E+10 | 1.001552 | 0.3771535E+11 | 1.197661 | 172486646 |
| -3 | 212376.3 | 191.2892 | 658366.6 | 112.0562 | 2840533 | 185.9757 | 13166298 | 86.50436 | 0.3036632E+10 | 1.048948 | 0.4054278E+11 | 1.184986 | 183656910 |
| -4 | 238923.4 | 190.4509 | 660136.4 | 100.1955 | 2893627 | 199.4633 | 12540657 | 91.31388 | 0.2801378E+10 | 1.101941 | 0.4414700E+11 | 1.071571 | 181408579 |
| 1983-1 | 212376.3 | 199.3221 | 617661.2 | 95.69850 | 2628157 | 215.4371 | 14755118 | 117.8762 | 0.2694634E+10 | 1.027831 | 0.3853239E+11 | 1.062622 | 157251721 |
| -2 | 345111.5 | 196.3564 | 693762.7 | 97.84707 | 3468813 | 216.5619 | 16702430 | 129.1923 | 0.3371549E+10 | 1.079965 | 0.4834298E+11 | 1.048431 | 193057126 |
| -3 | 398205.6 | 209.3704 | 826497.9 | 96.12736 | 3822774 | 211.2943 | 16406579 | 108.8276 | 0.3694998E+10 | 0.9121235 | 0.5637519E+11 | 1.104488 | 228227103 |
| -4 | 371658.6 | 173.5491 | 773403.8 | 81.64283 | 3291833 | 214.6039 | 15722594 | 106.3570 | 0.3500944E+10 | 1.011511 | 0.5169262E+11 | 1.115673 | 211904156 |
| 1984-1 | 380507.6 | 177.5434 | 679604.3 | 94.10889 | 2999816 | 219.9026 | 16609794 | 119.8690 | 0.3392829E+10 | 1.115098 | 0.4793776E+11 | 1.144093 | 201589123 |
| -2 | 566336.9 | 164.4234 | 792871.6 | 116.8492 | 3920113 | 210.8154 | 17789509 | 108.4385 | 0.3862345E+10 | 1.194938 | 0.5763511E+11 | 1.243622 | 258480334 |
| -3 | 628280.0 | 179.0241 | 888441.0 | 115.3193 | 3867019 | 228.1639 | 17746425 | 102.6252 | 0.3826954E+10 | 1.180882 | 0.6426891E+11 | 1.243907 | 284478292 |
| -4 | 610582.0 | 207.7374 | 835346.9 | 109.7575 | 3406870 | 229.4479 | 16630953 | 104.4690 | 0.3505268E+10 | 1.204328 | 0.6039643E+11 | 1.202479 | 258980052 |
| 1985-1 | 539789.9 | 200.1375 | 746856.8 | 110.1194 | 3035212 | 217.1800 | 15756234 | 110.1071 | 0.3280063E+10 | 1.270189 | 0.5693089E+11 | 1.242957 | 251340045 |
| -2 | 752166.2 | 204.2573 | 805260.3 | 102.1287 | 3716586 | 232.1107 | 19452358 | 124.1653 | 0.4076589E+10 | 1.229506 | 0.7015361E+11 | 1.219491 | 302825440 |
| -3 | 805260.3 | 223.5026 | 902599.4 | 96.30967 | 3902415 | 234.6266 | 18599219 | 110.4491 | 0.4111621E+10 | 1.238670 | 0.7917054E+11 | 1.197058 | 331872496 |
| -4 | 734468.2 | 209.7571 | 922067.3 | 98.19844 | 3796227 | 240.0406 | 17193446 | 105.0059 | 0.3827548E+10 | 1.216570 | 0.7755103E+11 | 1.191501 | 323131307 |
| 1986-1 | 637129.0 | 197.1469 | 822958.3 | 108.3931 | 3265286 | 242.1659 | 18095013 | 119.1529 | 0.3547038E+10 | 1.226327 | 0.6920952E+11 | 1.138673 | 280679978 |
| -2 | 902599.5 | 211.3908 | 854814.8 | 140.7783 | 4114791 | 254.9653 | 21013241 | 127.0773 | 0.4209168E+10 | 1.246671 | 0.8828057E+11 | 1.093748 | 341549234 |
| -3 | 982240.6 | 202.1759 | 999938.6 | 160.2051 | 4415658 | 250.4837 | 20392824 | 120.3361 | 0.4263190E+10 | 1.172095 | 0.1005851E+12 | 1.098310 | 385416955 |
| -4 | 822958.3 | 199.8529 | 959233.1 | 143.4441 | 3743133 | 239.9428 | 17187105 | 117.3502 | 0.3677498E+10 | 1.318190 | 0.8990491E+11 | 1.103667 | 347395025 |

[1] Source Appendix 1

[2] Quantity & price units for N, PT, P and L are cubic metres and $/cubic metres, respectively. Data for O and LBK are indexed N, PT, P, O and LBK stands for non-veneered wood panels, particleboard, plywood, lumber, other building materials and labor/capital, respectively.

[3] Q stands for quantity, P stands for unit price.

reports produced by the Resource Information System Inc. (RISI). However, only annual figures were reported (Table A1.3), and so it was assumed that the annual factors applied to each quarter of the respective year. The total quantities of consumption were then multiplied by the corresponding use factor (%) to obtain the quantities consumed by the Canadian construction industry.

**Table A1.3 Percent Of Total Domestic Consumption Of Selected Wood Products That Is Used By The Residential, Repairs & Alterations And Non-Residential Construction Industries.**

| | SHARES IN CANADA (%) | | | | SHARES IN THE U.S.(%) |
|---|---|---|---|---|---|
| YEAR | Non-veneered wood panels (NSP) | Particleboard (PT) | Plywood (P) | Lumber (L) | Lumber (L) |
| 1979 | 84 | 63 | 53 | 69 | 66 |
| 1980 | 81 | 58 | 51 | 67 | 62 |
| 1981 | 83 | 58 | 52 | 75 | 57 |
| 1982 | 78 | 57 | 50 | 78 | 64 |
| 1983 | 84 | 58 | 53 | 77 | 68 |
| 1984 | 79 | 57 | 50 | 76 | 68 |
| 1985 | 80 | 57 | 51 | 76 | 68 |
| 1986 | 84 | 58 | 53 | 76 | 69 |

Source: Resource Information Systems, Inc.

### A1.1.2 PARTICLEBOARD

Total shipments (including exports) and export shipments of particleboard produced in Canada were also collected from catalogue 36-003. Monthly unit prices of particleboard were calculated using the procedure that was used for NSP.

To compute domestic consumption of particleboard, however, total imports were needed since Canada is a consumer of imported particleboard. This data was collected from the Statistics Canada catalogue 65-007 (*Imports By Commodities*). Total domestic consumption of particleboard was then computed by first subtracting total exports from total shipments, and then adding total imports. Finally, these results were multiplied by the use factors provided by RISI (Table A1.3) in order to compute the amount of particleboard consumed by the three construction sectors.

### A1.1.3 PLYWOOD

The data on total domestic shipments of plywood was taken from the monthly Statistics Canada publication *Construction Type Plywood* (catalogue 35-001). From this publication, total domestic shipments of

Douglas fir plywood, "other" Canadian softwood plywood, and Poplar, Aspen and Cottonwood plywood were collected. It was assumed that these three categories of plywood adequately represent the plywood used by the construction industry.

Monthly data on softwood plywood imports were taken from Statistics Canada catalogue 65-007. Total domestic consumption of construction type plywood was then obtained by first summing the domestic shipments for the three plywood categories and then adding total softwood plywood imports. These results were then multiplied by the percent of plywood used in the three construction activities (refer to Table A1.3).

Plywood prices were developed from two sources; Madison's Lumber Reporter and Statistics Canada. Price data from Madison's are reported on a weekly basis and are direct car delivered prices from B.C. manufacturers to several Canadian destinations. Since "free on board" (f.o.b.) prices are required for this study, the delivered prices to Vancouver were used as a proxy for these prices. Unfortunately, however, data were only readily available for the 1979 - 1984 period. Therefore, the monthly producer price index (1971=100) for softwood plywood from the Statistics Canada publication *Industry Price Indexes* (catalogue 62-011) was used to complete the time series (1985 - 1986). This price index was converted to actual prices by multiplying the 1985 and 1986 monthly price indexes by the following conversion factor:[57]

$$\text{Conversion factor} = \frac{\text{December, 1984 actual price from Madison's}}{\text{December, 1984 producer price index}}$$

### A1.1.4 LUMBER

Total domestic shipments of Canadian lumber were collected from two monthly Statistics Canada publication; *Production, Shipments and Stocks on Hand of Sawmills East of the Rockies* (catalogue 35-002) and *Production, Shipments and Stocks on Hand of Sawmills in British Columbia* (catalogue 35-003). Domestic shipments from these two sources are an amalgamation of both hardwood and softwood lumber shipments. Since only about 24% of hardwood lumber is used in the three construction areas, compared to about 75% for softwood lumber, it was necessary to separate the data into the two lumber categories.

Fortunately, from the same catalogues, separate production data for the two categories of lumber were available. This allowed the production shares (percent) of each type of lumber from each catalogue to be computed. It was then assumed that these shares were equally applicable to domestic shipments which allowed the consolidated shipment data to be separated. It was found that on average about 1% of total lumber shipments from B.C. was hardwood species. For lumber produced by facilities east of the Rocky Mountains, the share of hardwood ranged between 3.3% to 9.9%.

To compute domestic consumption of both hardwood and softwood

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[57]This approach assumes that the computed conversion factor remains constant throughout the entire 1985-1986 period.

lumber, import data were collected from Statistics Canada catalogue 65-007. Total domestic consumption then equaled total domestic shipments plus total imports.

Finally, information was collected from two sources for computing the amount of lumber consumed by the three construction activities. For softwood lumber, the shares were supplied by industry reports produced by RISI (Table A1.3). For hardwood lumber, as noted earlier, it was assumed that for the entire study period 24% of total domestic consumption was by the three construction sectors. This latter assumption was based on information supplied by the Appalachian Hardwood Manufacturers.

Unit prices of hardwood lumber were constructed from data taken from the Statistic Canada publication *Exports By Commodities* (catalogue 65-004), since no other readily available source reported hardwood lumber prices. In this publication, exports of hardwood lumber are reported in both quantity (cubic metre) and value units which allowed unit prices to be determined. Two assumptions were made when constructing this price series. First, the data obtained were for the Poplar, Aspen and Cottonwood species. It was assumed that these prices were an adequate proxy for measuring price movements of all of the hardwood lumber used in the three construction activities. Second, since the data collected was of export shipments and not domestic shipments, it was assumed these prices represented price movements in the export market as well as the domestic market. The prices derived from this procedure are f.o.b. since the export data in value terms is net of transportation and duty charges. Hence, this latter assumption is not erroneous.

Two sources were used to generate softwood lumber unit prices; Madison's Lumber Trader and Statistics Canada Catalogue 65-004. From the former source, prices were only readily available for the period 1979-1982. This series was comprised of weekly prices of kiln dried Western spruce std/#2 & Btr. (2X4) f.o.b.. For the remaining time series (1983 - 1986), similar methodology employed for hardwood lumber prices was invoked. Export shipments -in value and quantity units- of white spruce lumber from catalogue 65-004 were used to complete the time series. Similar assumptions that were imposed when computing hardwood lumber prices from trade data were also applied for softwood lumber.

Finally, since a lack of data observations precluded the inclusion of each lumber category, hardwood and softwood lumber were aggregated into a single input. This was done using the Tornqvist discreet approximation to the Divisia index.[58] This index is only used for variables that are aggregated and is not used for single input items

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[58]Diewert (1976) urges that the Tornqvist index is more suitable for second-order cost functions than indexes such as the Laspeyres and Paasche. Hence, since the Generalized Leontief is a second-order approximation to a true cost function, the Tornqvist has been employed here. The first quarter of 1981 was used as the base year when generating this index and was used as the base year for all other variables aggregated in this study.

such as NSP, particleboard and plywood.

### A1.1.5 OTHER CONSTRUCTION MATERIALS

There are literally hundreds of materials used in the construction of residential and non-residential buildings. However, the cost to collect this amount of data would far exceed the benefits. Furthermore, it is not entirely evident that such extensive efforts would lead to "better" results. Nevertheless, this study attempts to include the non-wood materials that are most commonly used in the three construction activities.

Several authors have studied the demand for forest products by the *residential construction industry* and have focused on various products in their "other building materials" input.[59] Thus, based on these previous studies, availability of data, and the extension of this study to the *nonresidential* and *repairs & alterations construction industry*, data for thirteen non-wood materials were collected. The materials included are; building board, asphalt sheathing board, roof insulating board, other decorative board, hardboard, wall board (gypsum), concrete reinforcing bars, hot rolled sheets, cold reduced sheets, galvanized steel sheets, asphalt shingles, roofing asphalt and portland cement.

The shipment quantities for all thirteen products were taken from the Statistics Canada publication *Canadian Statistical Review* (catalogue 11-003E). This publication reported total shipments (includes exports) for wallboard and portland cement, and domestic shipments for the other materials. To derive domestic shipments for wallboard and portland cement export data for these two goods were obtained from Statistics Canada catalogue 65-004.

Before domestic consumption could be computed, the amount of total shipments and imports of the thirteen materials used in the construction industry was required. Fortunately, for concrete reinforcing bars, hot rolled sheets, cold reduced sheets & strip and galvanized steel sheets, only those domestic shipments destined to the construction industry were reported. However, the import data for these products included shipments to all end-uses. Therefore, the percent of total consumption used by the construction industry needed to be determined so that the import data could be adjusted. This information was derived from Statistics Canada catalogue 41-001 (*Primary Iron And Steel*). In this catalogue, quantities of shipments are reported separately for each end-use which allowed the percent of total

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[59] In their study of the U.S. residential construction industry, McKillop et al (1980) focused on portland cement, galvanized carbon steel sheets and aluminum extruded shapes as the main substitutes for softwood lumber and plywood. Rockel and Buongiorno (1982), on the other hand, included structural steel products, cement products, structural clay products, plumbing fixtures, and heating equipment in their study of the same industry. Finally, in analyzing both the Canadian and U.S. construction industry, Sharma (1986) assumed that aluminum, bricks, clay, cement, plumbing, air conditioning, reinforced bars, and steel were the main non-wood materials used.

shipments destined to the construction industry to be derived.[60] It was found that the average share of concrete reinforcing bars, hot rolled sheets, cold reduced sheets, and galvanized steel sheets used in construction applications were 64%, 5%, 5% and 32%, respectively. Import shipments, which were collected from cat. 65-007, were then multiplied by these shares contingent upon the assumption that these shares could be equally applied to the import data. Lastly, it was assumed that 100% of domestic shipments and imports of the remaining materials was by the construction industry.

Finally, domestic consumption for each of the thirteen materials were computed by adding import shipments to domestic shipments.

Actual unit prices for each of the thirteen materials were computed from two series. First, price indexes for all materials were collected from Statistics Canada catalogue 62-011. Second, in order to computed actual prices from these indexes, an actual price for the first month of 1981 was calculated from value and quantities of exports for each material which were reported in catalogue 65-004. From these two sets of information, a conversion factor for each material was computed.

$$\text{Coversion factor} = \frac{\text{Actual price of the ith material in Jan. 1981}}{\text{Price Index of ith material in Jan. 1981}}$$

The conversion factors were then multiplied by the price indexes to yield actual prices. The thirteen non-wood materials were then aggregated into a single input using the Tornqvist index.

### A1.1.6 LABOR

The labor variables used in this study consisted of both salaried and "paid by the hour" construction workers. Data on number of employees, average weekly hours worked (including overtime) and average hourly earnings (including overtime) were collected for both classes of construction workers. All data were obtained from Statistics Canada catalogue 75-002 (*Employment, Earnings and Hours*).[61]

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[60]From cat. 41-001, domestic shipments destined to steel fabrication, metal building systems, and contractor's products were used to calculate the share of shipments destined to the construction industry.

[61]The methodology used by Statistics Canada to collect labor data had changed in March, 1983. Therefore, the data prior to this date had to be transformed so that they were comparable to data reported from 1983 onward. Fortunately, Statistics Canada reported labor statistics for March, 1983 under the old and new methodology. This allowed a conversion factor to be computed which was used to transform all data points prior to March, 1983.

Moreover, prior to March, 1983, Statistics Canada did not report the average weekly hours worked for construction workers on salary. Thus, it was assumed that the average weekly hours worked prior to this date was 38.5 hours which was based on an average for the March to December, 1983 period.

The quantity of labor for each class of workers was derived by multiplying average weekly hours worked per employee by 12.5 weeks per quarter period, and then by the number of employees. This yielded quantity units of hours worked per quarter period. The average hourly earnings ($/hour) were used as the unit price of labor. The labor variables for the two different categories were then combined into a single variable using the Tornqvist index.

**A1.1.7 CAPITAL**

Three pieces of information are required to calculate the rental price of capital; price of new investment goods (i.e., the replacement cost of capital); the economic depreciation rate; and the rate of return to capital (i.e., opportunity cost of capital).

The only proxy available for the price of new capital in the construction industry is a price index for machinery and equipment used in the construction sector. This index was collected from the *Canadian Statistical Review*. It should be pointed out that this data series provides a measure of machinery and equipment prices movements in all construction sectors. As a result, this aggregated index may not adequately represent price movements in the three construction areas examined in this study. It must also be noted that the capital used by the residential and non-residential construction industry is comprised predominantly of service and human capital while the index used is of physical capital. Since this data series is the only one readily available, however, it is the one used here.

There is a substantial body of literature, both theoretical and technical, on the measurement of the economic depreciation rate. Some practitioners and theorists have argued that physical capital depreciates at a geometric rate while others have advocated that a straight-line depreciation rate is more realistic. Determining which approach fits the depreciation rate of construction capital is left for other research, and so the straight-line method has been arbitrarily chosen here.

A quarterly straight-line depreciation rate (DR) is computed as follows:

DR = ((3/12)/SL)*100

where: SL is the service life of the capital assets. From Statistics Canada publication *Fixed Capital Flows and Stocks* (catalogue 13-568), an average service life of 26 years for capital employed in the construction industry was used. This results in a depreciation rate of 0.96%.

The final variable is the rate of return to capital. The two most commonly used proxies for this variable are the ex-post corporate rate

of return and the ex-post corporate bond yield.[62] The latter approach is adopted here since it is very time consuming to obtain the amount of taxes that have been paid on capital by the construction industry. Given this, the proxy used for the rate of return (opportunity cost) on capital was the Canadian Bond Yield Averages (McLeod, Young & Weir) of weighted long-term corporate bonds which were acquired from the *Bank of Canada Review*.

The variable needed for estimation - the rental price of capital ($r_t$) - was derived using the data described above and the following formula

$$r_t = p_t\ (i + DR);$$

where: p is the price of new capital investment; $i$ is the opportunity cost; DR is the depreciation rate; and $t$ denotes the time period (quarters).

Data on quantity of capital used in the construction industry were not available. This variable was constructed from the cost shares of the other factor inputs used in this study and the rental price of capital (r). Since the cost shares of all factor inputs must sum up to one, the quantity of capital ($K_Q$) can be derived using the following two equations:

$$(1)\quad S_K = 1-[S_N + S_{PT} + S_P + S_L + S_O + S_{LB}]$$

$$(2)\quad K_Q = \frac{S_K \times TC}{r}$$

where: $S_i\ \forall\ i;\ i = N, PT, P, L, O, LB$

is cost shares of each input; and TC is total cost (refer to section A1.1.7 for details on total costs).

Finally, the price and quantity index of labor were aggregated, using the Tornqvist index procedure, with the price and quantities of capital to form a single labor/capital variable. This was done in order to reduce the number of parameters in the partial adjustment models.

### A1.1.8 CONSTRUCTION INDUSTRY

The final variable needed was a measure of industry output. Since this variable was not available, an output index was constructed from total expenditure data - a proxy for total costs of production - and an output price index. These variables are explained below.

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[62] The ex-post corporate rate of return is a more "realistic" measure since it is an "after-tax rate of return" thus accounting for the fact that investors within an industry do not anticipate a 'riskless' rate of return. The ex-post corporate bond yield approach assumes that investors expect a return on their investment which corresponds to the type of return achieved in industrial production of the nature they are engaged in.

Investment expenditures for the residential (including R&A) and non-residential construction sector published in Statistics Canada *National Income & Expenditures Accounts* (catalogue 13-001) were used as a proxy for the total cost of production for these sectors. Using investment expenditures implies an assumption of constant returns to scale in these industries. Unfortunately, the inavailability of cost data does not permit this assumption to be tested thus it is regarded as a maintained hypothesis in this study.[63]

The proxies used for output prices were the historical residential and non-residential price deflators. These two series were taken from Statistics Canada catalogue 62-007 (*Construction Price Statistics*). These price deflators represent the movement of the ratio of investment in residential and non-residential construction measured in current dollars to investment measured in constant dollars. Like the variable used for the price of capital, these indexes may be imperfect because they describe output in a number of construction sectors (i.e., single, multi-family homes, apartment complexes, etc.) and not just the three areas analyzed in this study. Nonetheless, this is the only proxy available.

A measure of output for these two sectors, keeping in mind that residential construction includes R&A, were obtained simply by dividing total expenditures in each industry by their respective output price.

Finally, a Tornqvist index of price and quantity of output for the two sectors was computed.

## A1.2 UNITED STATES

### A1.2.1 NON-VENEERED STRUCTURAL WOOD PANELS (NSP)

Domestic consumption of NSP by the three construction industries and unit prices of NSP in the United States were available through the Resource Information Systems, Inc. (RISI).[64]

The unit prices of NSP are Chicago delivered prices. Since these were the only prices readily available, it was assumed that transportation margins over the study period have not changed, hence these prices provide a true reflection of changes in demand and supply conditions in the U.S. NSP market.

### A1.2.2 PARTICLEBOARD

Domestic consumption of particleboard by the three U.S.

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[63]The assumption of constant returns to scale may be appropriate in the long-run but it is unlikely to hold in the short-run. This is because over- and under-shooting of factor demands to a change in output demand can occur in the short-run.

[64]RISI supplies separate NSP domestic consumption data for the following six end-use categories: single-family homes, multi-family homes, mobile homes, non-residential construction, repairs & alterations, and industrial markets. Since, as noted previously, the industrial markets are not included in this study, the first five categories were summed. These data source eliminated the need to collect trade data.

construction industries was also obtained from RISI.

Monthly unit prices of particleboard were taken from the Random Lengths Yearbook which is published by Random Lengths Publications, Inc.. Prices for Western Particleboard (3/8", interior underlayment, net f.o.b.) were used to reflect price movements of particleboard in the U.S..

### A1.2.3 PLYWOOD

Domestic consumption of softwood plywood by the three U.S. construction industries was also obtained from RISI. Separate end-use data were reported for both rough and sanded softwood plywood; these two products were summed together.

Prices of U.S. produced softwood plywood were collected from the Random Lengths Yearbook. In the Yearbook, prices for 24 different types and sizes of softwood plywood are supplied. Prices of Western Plywood 3/8" CD Exterior were used for the purpose of this study. The movement in these prices were compared to a composite price index of all softwood plywood, which was collected from the U.S. Dept. of Labor *Producer Price Indexes*, and were found to be almost identical. It follows therefore that the actual prices used adequately represent historical price movements in the entire U.S. plywood market.

Hardwood plywood was not included in this study since neither price or consumption data were easily obtainable.

### A1.2.4 LUMBER

Quarterly data on imports, exports and shipments of softwood lumber in the U.S. were supplied by the National Forest Products Association. Domestic consumption of lumber were derived by subtracting exports from shipments and then adding imports. Hardwood lumber was not included in this study because of data inavailability.

In order to compute the amount of lumber consumed by the three construction activities, total domestic consumption were multiplied by the end-use shares provided by RISI for the U.S. (Table A1.3).

Unit prices for lumber in the U.S. were taken from the Random Lengths Yearbook. In this Yearbook, a composite price series of framing lumber is supplied.[65] This price series was used since it represents a broad measure of price movements in the lumber market.

### A1.2.5 OTHER BUILDING MATERIALS

The 'other materials' input for the U.S. construction industry is comprised of six products: concrete reinforcement bars, galvanized steel sheets, portland cement, gypsum products, hot rolled sheets, and cold rolled sheets.

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[65]This composite price is a weighted average of the prices of nine types of framing lumber: Std & Btr 2x4s of Kiln dried Southern Pine (westside), #2 & Btr 2x10s of KD Fir & Larch, KD Southern Pine, studs of KD Southern Pine, three grades of green Douglas fir and two grades of KD Western S-P-F (refer to p. 170 of the Random Lengths Yearbook).

Total shipments (includes exports) of these six materials were taken from the U.S. Department of Commerce, International Trade Administration, *Construction Review*. In order to compute domestic consumption of these products, trade data were also required.

Export shipments for these products were collected from the U.S. Dept of Commerce, Bureau of the Census publication *U.S. Exports Commodity by Country* (catalogue FT410). Import shipments were collected from the U.S. Dept. of Commerce, Bureau of the Census publication *U.S. General Imports Commodity by Country* (catalogue FT135). Domestic consumption was then computed by subtracting export shipments from total shipments and then adding import shipments.

Finally, based on shares used for the Canadian construction industry, it was assumed that 64% and 32% of domestic consumption of concrete reinforcement bars and galvanized steel sheets, respectively, were used in the U.S. construction industry. It was further assumed that all portland cement and gypsum was consumed by the construction industry. Lastly, from information contained in the *Statistical Abstract of the United States* (published by the U.S. Dept. of Commerce, Bureau of the Census), it was found that on average 10.18% of total consumption of cold reduced and hot rolled sheets was by the U.S. construction industry.

Actual unit prices of concrete reinforcement bars, gypsum, hot rolled sheets, cold reduced sheets and galvanized steel sheets were derived from the export data in catalogue FT410. In this publication, both value and quantity of export shipments are reported. Prices were derived by dividing the value of export shipments by the quantity of export shipments. By using this procedure, it has been assumed that the prices calculated are f.o.b. and that they represent price movements in the domestic market.

Since the U.S. does not export portland cement, actual unit prices could not be determined from export data. To get unit prices a price index for this good was taken from the U.S. Dept of Labor, Bureau of Labor Statistics publication *Producer Price Indexes*. Then, an actual price of portland cement for 1981 was collected from the *Statistical Abstract of the U.S.*. From this price and the price index for the first quarter of 1981, a conversion factor was computed:

$$\text{Conversion factor} = \frac{\text{Actual price in 1981}}{\text{Price index for 1st quarter in 1981}}$$

This conversion factor was then multiplied by the entire price index time series to yield actual prices. This procedure was done under the assumption that the conversion factor remained constant throughout the entire sample period.

Lastly, the Tornqvist index was used to combined these six products into a single input.

### A1.2.6 LABOR

Three data series were used to construct the quantity and price variables for labor employed by the U.S. construction industry. They are number of employees in general building contractors, average weekly hours worked by general building contractors and average hourly

earnings by general contractors; all series were collected from the *Construction Review*.

The quantity of labor variable ($\bar{x}$ hours/quarter) was constructed as follows:

$\bar{x}$ hours/week/employee * 12.5 weeks/quarter * # employees

Average hourly earnings ($/hour) were used as a proxy for the unit price of labor.

### A1.2.7 CAPITAL

The rental price of capital used in the U.S. construction industry was constructed using the same methodology employed for the Canadian industry (refer to A1.1.7).

A price index of machinery & equipment used by the construction industry was used as a proxy for the price of new capital paid by construction firms. Again, as noted for Canada, this series is far from ideal since construction capital is comprised of many forms, not just physical capital (i.e., machinery & equipment). Nevertheless, this is the only proxy available. This price index was taken from *Producer Price Indexes*.

Average yields of new Aa corporate bonds were used as a proxy for the opportunity cost faced by construction firms when investing in productive capital. The source of these yields was the *Treasury Bulletin* (published by the Office of the Secretary, Dept. of the Treasury).

Like the the Canadian capital variable, a straight-line depreciation rate was used, and a capital service life of 26 years was assumed.

Finally, the quantity of capital used by the construction industry was also generated using the methodology employed for the Canadian data since it was virtually impossible to collect quantity data for each type of capital used in the construction industry.

### A1.1.8 CONSTRUCTION INDUSTRY

The data for the U.S. construction industry were constructed using the same approach that was used for the Canadian industry.

Investment expenditures by both private and public agencies were used as a proxy for cost of production. As noted for Canada, this implies a maintained hypothesis of constant returns to scale in the U.S. construction industry. Three series, which were taken from the *Construction Review*, were used to generate this variable. They included: expenditures on residential construction by private agencies (includes expenditures on repairs & alterations), expenditures on non-residential construction by private agencies and expenditures in construction by public agencies (buildings only). These monthly series were summed to generate a single measure of cost of production.

Since no actual prices of output by the three construction industries in the U.S. were available, the producer price index for construction materials was used as a proxy for the price of construction. This index was collected from the *Supplement to Producer Price Indexes* which is published by The U.S. Dept. of Labor, Bureau of

Labor Statistics. Output was then derived by dividing total expenditures by the price index.

### A1.3 SCALING THE DATA

Several of the models proposed in this study are estimated with a non-linear optimization routine. In order to increase the probability that the optimization procedure converges and converges at a global level, some of the variables were scaled.

The data shown in Tables A1.1 and A1.2 are unscaled. Before any of the models were estimated, these data were scaled as follows: Quantity of plywood, lumber, other building materials, labor/capital, and industry output for the Canadian industry were divided by 10, 10000, 10000, 100000 and 1000000, respectively. For the U.S. data, quantities of particleboard, plywood, lumber, other building materials, labor/capital and industry output were divided by 10, 100, 100, 100000, 1000000 and 10000, respectively.[66]

### A1.4 DATA CAVEATS

There are several caveats associated with the construction of the data that should be stressed. In order to construct a measure of industry output it was necessary to assume that total revenue equals total cost in both the short- and long-run. This assumption may hold in the long-run but, since over- and under-shooting of factor demands to changes in output demand can occur in the short-run, it may not hold in the short-run.

A second warning is in regard to input aggregation; namely the aggregation of labor/capital and the "other" building materials input. It was assumed that the goods that make up an input are separable. In some cases this assumption may be unrealistic which may affect the estimated parameters. However, given the nature of the data, separability could not be tested for.

Finally, the aggregation of several new wood panel products into the NSP input does not permit changes in product characteristics to be measured very well. Thus some caution should be exercised when using the results to understand the behavior of the construction industries towards an individual product from the NSP group (i.e., waferboard). Nonetheless, the results obtained for NSP in this study do reveal how the construction industries have behaved towards these products as a group.

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[66]No attempt was made to 'unscale' the estimated parameters that were generated from the models since many of the models included interdependent terms that were difficult to 'unscale'. Nonetheless, this does not preclude us from obtaining estimates of the various structural measures (i.e., elasticities), nor does it affect the inference tests that are used in this research. It should be pointed out, however, that the elasticities of substitution had to be computed using the 'scaled' predicted cost shares (refer to section 4.1.5.2).

## A1.5 INSTRUMENTAL VARIABLES

In this study it is argued that, since the construction industry is the principal consumer of the factor inputs being analyzed, factor input prices are not exogenous. To correct for the possible correlation between the dependent and independent variables, the instrumental variable estimator technique described by Judge et al (1985, pp 168-169) was used.

When using this technique, a difficulty in choosing instruments that are correlated with the explanatory variable and yet uncorrelated with the error term arises. No formal statistical test is performed to see which instruments satisfy these criteria. Instead, the criteria used to select the instruments for this study is that the instruments should be exogenous to the construction industry but endogenous to the macroeconomic system in which the industry operates. Given this criteria and a priori knowledge of the industry, the instruments reported in Tables A1.4 and A1.5 were chosen for the Canadian and U.S. construction industry, respectively.

The instrument variables were regressed against actual unit prices of each of the six factor inputs. The predicted values generated from these regression were then used in the final models. The instruments regressed on each of the prices are reported in Tables A1.6 and A1.7 for Canada and the United States, respectively along with the corresponding correlation coefficients.

**Table A1.4: Explanation and Source Of The Instrumental Variables Used In The Models Of The Canadian Construction Industry.[1]**

| SYMBOL | | DESCRIPTION | SOURCE |
|---|---|---|---|
| C1 | - | Population | Canadian Statistical Review |
| C2 | - | Industrial Producer Price Index of all Commodities | Canadian Statistical Review |
| C3 | - | Can./U.S. Exchange Rate | Bank of Canada Review |
| C4 | - | Gross Domestic Product | Bank of Canada Review |
| C5 | - | Bank Rate | Bank of Canada Review |
| C6 | - | Time Trend[2] | |
| C7 | - | Average Weekly Earnings/ Industrial Aggregate | Canadian Statistical Review |
| C8 | - | Lagged Quantity of NSP[3] | Refer to Appendix 1 |
| C9 | - | Lagged Quantity of PT | Refer to Appendix 1 |
| C10 | - | Lagged Quantity of P | Refer to Appendix 1 |
| C11 | - | Lagged Quantity of L | Refer to Appendix 1 |
| C12 | - | Lagged Residential Construction Expenditures | Refer to Appendix 1 |
| C13 | - | Lagged Non-residential Construction Expenditures | Refer to Appendix 1 |
| C14 | - | U.S. Housing Starts | Construction Review |
| L | - | Natural Logarithm | |

[1] All variables pertain to Canada unless otherwise noted.
[2] t=1 for 1979-2, t=2 for 1979-3, etc.
[3] All lagged variables were lagged one quarter period.

**Table A1.5: Explanation And Source Of The Instrumental Variables Used In The Models Of The United States Construction Industry.**[1]

| SYMBOL | | DESCRIPTION | SOURCE |
|---|---|---|---|
| U1 | – | Gross Domestic Product | Business Conditions Digest |
| U2 | – | Population | Business Conditions Digest |
| U3 | – | Index of Industrial Production | Business Conditions Digest |
| U4 | – | Time Trend[2] | |
| U5 | – | Lagged Quantity of NSP[3] | Refer to Appendix 1 |
| U6 | – | Lagged Quantity of PT | Refer to Appendix 1 |
| U7 | – | Lagged Quantity of P | Refer to Appendix 1 |
| U8 | – | Lagged Quantity of L | Refer to Appendix 1 |
| U9 | – | Average Hourly Earnings[4] | Business Conditions Digest |
| U10 | – | Producer Price Index, All commodities | Business Conditions Digest |
| U11 | – | Average Prime Rate Charged by Banks | Business Conditions Digest |
| U12 | – | Lagged Quantity of O | Refer to Appendix 1 |
| U13 | – | Lagged Quantity of LBK | Refer to Appendix 1 |
| L | – | Natural Logarithm | |

[1] All variables pertain to the United States unless otherwise noted.
[2] t=1 for 1979=2, t=2 for 1979-3, etc.
[3] All lagged variables were lagged one quarter period.
[4] This variable is the average hourly earnings of production of nonsupervisory workers on private nonagricultural payrolls.

**Table A1.6: A List Of The Instruments That Were Regressed On The Prices Of The Six Inputs In The Canadian Models And The Corresponding Correlation Coefficients ($R^2$).**

| DEPENDENT VARIABLE[1] | INSTRUMENTS[2] | $R^2$ |
|---|---|---|
| NSPP | LC1,LC2,LC3,LC4,LC5,LC6,LC7,LC8,LC9,LC10 | .8790 |
| LPTP | LC1,LC2,LC3,LC4,LC5,LC6,LC7,LC8,LC9,LC10 | .9748 |
| PP | LC2,LC3,LC5,LC6,LC7,LC8,LC9,LC10 | .8558 |
| LP | LC1,LC2,LC3,LC4,LC5,LC6,LC7,LC11,LC12,LC13,LC14 | .8403 |
| LOP | LC1,LC2,LC3,LC4,LC5,LC6,LC7 | .9921 |
| LLBKP | LC1,LC2,LC3,LC4,LC5,LC6,LC7 | .9881 |

[1] NSPP is the price of structural non-veneered panels; LPTP is the logged price of particleboard; PP is the price of plywood; LP is the price of lumber; LOP is the logged price of "other building materials"; and LLBKP is the logged price of the labor/capital variable.

[2] An explanation of the symbols associated with the instruments are given in Table A1.4. An L in front of the instrument means it was logged.

**Table A1.7: A List Of The Instruments That Were Regressed On The Prices Of The Six Inputs In The U.S. Models And The Corresponding Correlation Coefficients ($R^2$).**

| DEPENDENT VARIABLE [1] | INSTRUMENTS [2] | $R^2$ |
|---|---|---|
| NSPP | LU1,LU2,LU3,LU4,LU5,LU6,LU7,LU9,LU10 | .7543 |
| PTP | LU1,LU2,LU3,LU4,LU5,LU6,LU7,LU9,LU10,LU11,LU12 | .7954 |
| PP | U1,U2,U3,U4,LU5,LU6,LU7,U9,U10,U11 | .7900 |
| LP | LU1,LU2,LU3,LU4,LU8,LU9,LU10,LU11,LU12 | .7140 |
| OP | U1,U2,U3,U4,U9,U10,U11,LU12 | .8969 |
| LLBKP | LU1,LU2,LU3,LU4,LU9,LU10,LU11,LU13 | .9819 |

[1] NSPP is the price of structural non-veneered panels; PTP is the price of particleboard; PP is the price of plywood; LP is the price of lumber; OP is the price of "other building materials"; and LLBKP is the logged price of the labor/capital variable.

[2] An explanation of the symbols associated with the instruments are given in Table A1.5. An L in front of the instrument means it was logged.

**Appendix 2**

**Figure A2.1: Predicted Input/Output Demands From The Partial Adjustment Model With Time Versus Actual Demands, Canadian Construction Industry.**

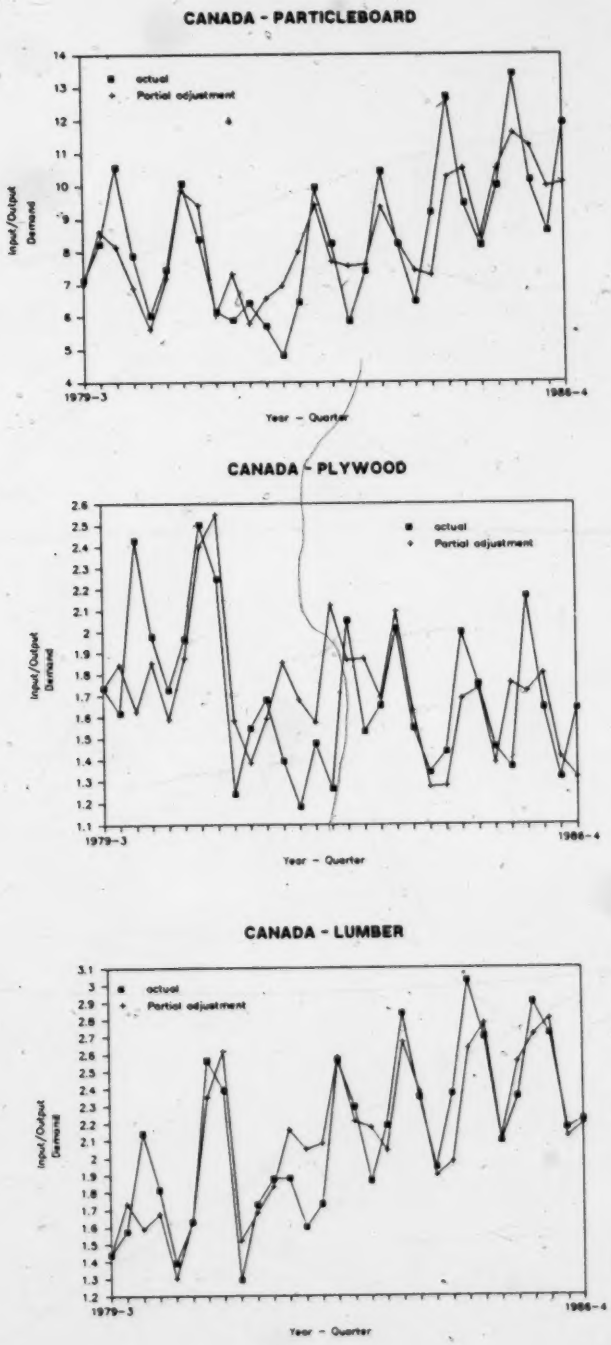
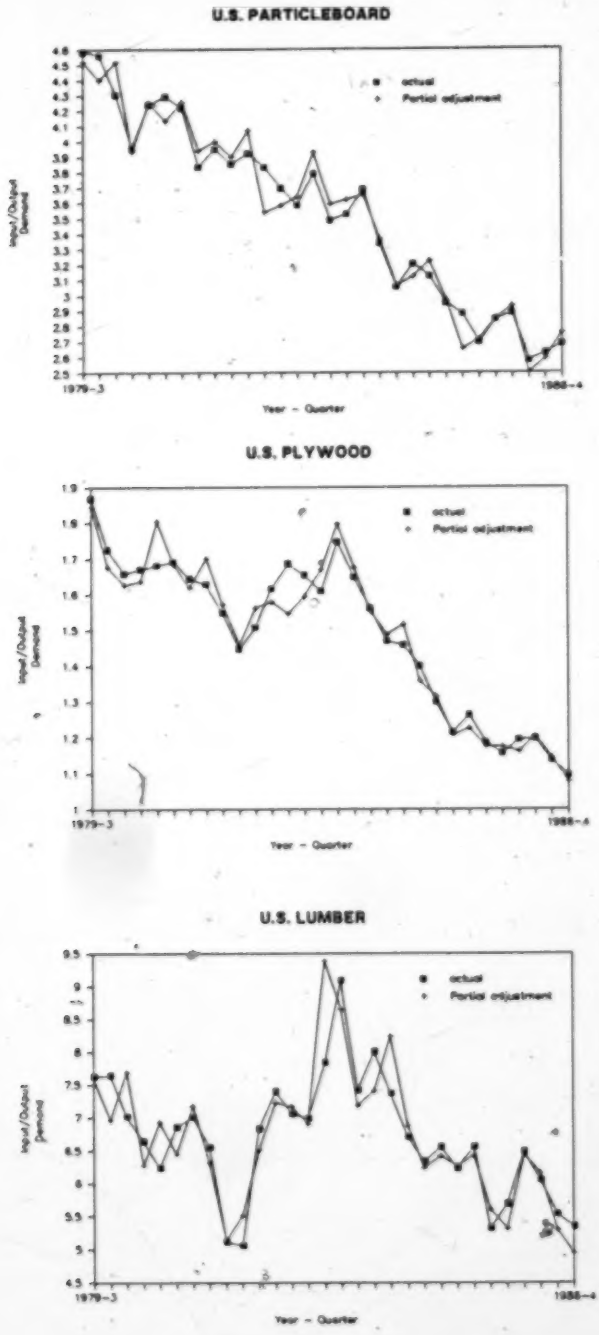
**Figure A2.2: Predicted Input/Output Demands From The Partial Adjustment Model With Time Versus Actual Demands, United States Construction Industry**